PREFABRICATED AIRFIELD AND ROAD SURFACING MEMBRANE INVESTIGATION

ENGINEERING TESTS, JANUARY 1956 - DECEMBER 1959

TECHNICAL REPORT NO. 3-492

Report 2

October 1962

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. PREFABRICATED AIRFIELD AND ROAD SURFACING MEMBRANE INVESTIGATION; ENGINEERING TESTS, JANUARY 1956-DECEMBER 1959, by S. G. Tucker. October 1962, viii, 49 pp and appendix - illus - tables. (Technical Report No. 3-492, Report 2)

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UNCLASSIFIED

1. Membrane
2. Textiles
3. Pavements
4. Surfacing

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ARMY-MRC VICKSBURG, MISS.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES

PREFACE

This report describes an investigation conducted for the development of a flexible prefabricated membrane suitable as an expedient dustproofing and waterproofing medium for soil subgrades when placed under landing mat or as a surfacing without mat. The general authority for the investigation reported herein was contained in the Research and Development Project Card for Project 8-70-03-101,* "Prefabricated Airfield and Road Surfacing Membrane," a copy of which is included as Appendix A.

The laboratory and engineering traffic tests pertinent to this investigation were performed at the U. S. Army Engineer Waterways Experiment Station (WES) during the period January 1956-December 1959. Engineers of the WES Soils Division who were actively engaged in the planning, testing, analysis, and report phases of the investigation were Messrs. W. J. Turnbull, A. A. Maxwell, W. L. McInnis, and S. G. Tucker. This report was prepared by Mr. Tucker.

The views contained in this report have not been approved by the Department of the Army, and represent only the views of the WES.

Directors of WES during the conduct of this study and the preparation and publication of this report were Col. A. P. Rollins, Jr., CE, Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany

* Now under Task 05 of Project 8S70-05-001.

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SUMMARY

Laboratory and field tests were conducted on four coated fabrics to determine their suitability (a) as dustproofing and waterproofing media when placed directly on soil subgrades, and (b) as an expedient means for dustproofing and waterproofing soil subgrades beneath the M8 steel landing mat. A T1, vinyl-coated cotton duck membrane which had been tested previously was used as a basis for comparison. Nylon membranes tested were: (a) the T12, a neoprene-coated nylon membrane; (b) the T13, a vinyl-coated nylon membrane; and (c) the T14, a neoprene-coated nylon membrane with embossed surface to improve skid resistance when wet.

From laboratory tests of 11 adhesives, four were selected for field tests to determine their suitability for sealing membrane lap joints and resisting the exhaust blast of jet aircraft. Sewn membrane panels, devised to decrease the quantity of materials required, increase the membrane placement rate, and decrease the number of adhesive lap joints, were also tested.

In the laboratory, the weight, tensile and tearing strengths, elongation, permeability, and resistance to flame, heat, fuel spillage, and weathering of membranes and/or adhesives were determined. In the field, adhesive-bonded and sewn membrane panels were placed on the subgrade with and without landing mat and subjected to accelerated traffic of a 50,000-lb single-wheel load (at a 200-psi inflation pressure) which was applied in a precise pattern to simulate aircraft traffic normally placed on a hastily prepared combat-type airfield or road.

Results of the tests indicated the following:

a. The T12, neoprene-coated nylon membrane was the most satisfactorily performing surfacing material tested either as a wearing surface without landing mat or when used beneath the landing mat. However, considerable wrinkling or puckering at the selvage prevented rapid construction and adequate bonding of adhesive joints.

b. All membranes provided adequate dustproofing of the subgrade beneath the landing mat; however, only the T12 membrane was considered waterproof for 700 coverages when used beneath the M8 mat. In the membrane-surfaced sections, only the nylon membranes (T12, T13, and T14) were considered waterproof for 700 coverages of the test wheel. Particles such as gravel or

slag punctured the vinyl-coated cotton duck membrane, but not the nylon membranes.

c. The sewn membrane panels were placed approximately nine times faster than adhesive-bonded panels.

d. Vinyl adhesive SBP-1146-A and neoprene adhesive G-580 were the best performing adhesives tested.

e. Membranes and sewn joints performed satisfactorily when exposed to jet aircraft exhaust blast at a temperature of 365 F for 5 min, but the adhesive joints were not satisfactory.

f. When wet, the embossed surface of the neoprene-coated nylon membrane did not improve the skid resistance.

Based on results of the investigation, it is recommended that engineering tests be conducted with improved all-weather connecting media, such as mechanical fasteners, for membrane strips and panels. Also, cooperative studies should be undertaken with fabric manufacturers and coaters to effect improvements in the manufacturing and coating processes of nylon membrane materials and to eliminate undesirable characteristics such as selvage pucker.

PREFABRICATED AIRFIELD AND ROAD SURFACING

MEMBRANE INVESTIGATION

ENGINEERING TESTS, JANUARY 1956-DECEMBER 1959

PART I: INTRODUCTION

Background

1. The Prefabricated Bituminous Surfacing (PBS) membrane used during World War II is too limited in availability of materials, strength, and durability in storage to satisfy Armed Forces requirements for a prefabricated membrane for surfacing roads and airfields in Theaters of Operations. It is also unsatisfactory for use in areas of extreme temperatures. In addition, the development and increasing use of jet aircraft and heavier wheel loads have accentuated the drawbacks of PBS, since the material is not resistant to jet fuels, or to jet aircraft exhaust blasts and elevated temperatures. Consequently there is a need for an improved type of prefabricated membrane for use in dustproofing and waterproofing soil bases on which landing mats are to be placed, and for temporary surfacing of roads and runways where subgrade strengths are adequate to sustain traffic without the load-spreading capabilities of landing mat. (See Appendix A for details of requirements.)

2. During the period from the fall of 1952 through the summer of 1954, the Air Proving Ground Command, Eglin Air Force Base, Florida, conducted comparative and operational suitability tests of waterproofing and dustproofing membranes under Project No. APG/CSC/244-A. A final report of the tests was published 29 November 1954, and a conference, arranged by the U. S. Air Force for the purpose of discussing future plans for development of an improved membrane material, was held at Eglin Air Force Base on 18-19 June 1955. Recommendations of the report and conference served as a basis for the formulation of this study to develop:

- a. Two types of membranes, one for use under landing mat and the other for use as a surfacing without landing mat
- b. A membrane with adequate elongation or stretching ability to

permit its conformance to the contours of the landing mat

c. A membrane surface treatment to provide adequate skid resistance when the membrane is wet

d. Suitable adhesives and methods other than adhesives for joining strips of membrane in the field

3. In Report 1 of this series the T1, vinyl-coated cotton duck membrane was found to be the best of the còtton, rayon, or dacron fabrics tested. However, it did not prove satisfactory in open-weather storage tests. None of the adhesives used in the tests reported in Report 1 were satisfactory. Based on the results of the earlier investigations and the added requirements imposed by use of jet aircraft, it was decided to test nylon fabrics, coated with neoprene or vinyl resin, which it was hoped would have greater strength, elasticity, and durability than the fabrics tested previously.

Purpose and Scope of Study

4. The purpose of this study was to evaluate various types of coated fabrics, adhesives, and methods of joining membranes in the field, and to determine their suitability as expedient surfacing for waterproofing and dustproofing hastily prepared airfields and roads. The specific objectives of this investigation were to:

a. Evaluate neoprene- and vinyl-coated nylon membranes.

b. Compare physical characteristics and field performance of the T1, No. 8 cotton duck (the best of the membranes previously investigated) and the vinyl- and neoprene-coated nylon membranes.

c. Evaluate neoprene and vinyl adhesives.

d. Evaluate the field performance of sewn membrane panels.

e. Obtain laboratory data on the various membranes and adhesives.

f. Determine the most satisfactory means for joining membrane in the field.

g. Obtain factual information and data concerning membrane materials when exposed to jet aircraft exhaust blasts and aircraft traffic.

h. Compare the time rates for placing sewn membrane panels and adhesive-joined membrane strips.

i. Determine the skid resistance provided by an embossed membrane surface when wet.

j. Evaluate the effects of landing mat placed on membranes under traffic.

5. These objectives were accomplished by means of:

a. Laboratory tests of membranes and adhesives to determine such properties as weight, tensile strength, elongation, and resistance to heat, fire, weather, etc.

b. Construction of test sections surfaced with various membranes both with and without landing mats

c. Traffic tests on the test sections with a 50,000-lb single-wheel load and a tire inflation pressure of 200 psi

d. Skid-resistance tests on both dry and wet membrane surfaces with locked pneumatic-tired wheels

e. Blast tests on membranes and mats using a jet aircraft

Definitions of Pertinent Terms

6. For clarity, the meanings of certain terms used in this report are given below.

Test area

Test section. An area in which one type of membrane was placed under one set of conditions.

Test lane. The area in which all test sections were located.

Traffic lane. Area in which the coverages by the test vehicles (described below) were controlled so that an exact rate and pattern of traffic were obtained.

Soil subgrade. Those soils, either processed or nonprocessed, upon which the membrane or landing mat was placed.

In-place density. The dry weight of soil, in pounds per cubic foot, existing in the subgrade at a particular time.

CBR. The California Bearing Ratio of the soil (an evaluation of the soil's ability to resist shear deformation) measured in the field (see Corps of Engineers test procedure in Appendix III of EM 1110-45-302).

Membrane, landing mat, and adhesive

Run. A strip equal to one width of the membrane or landing mat

reaching across an entire test section.

Overlap. The amount, in inches, that one run of membrane covers an adjacent run of membrane.

Warp. The direction parallel to the long axis of the runs or strips of membrane.

Vinyl. Any of a group of thermoplastic resins formed by the polymerization of a vinyl compound. Resins of this group are resistant to chemical agents and are used for surface coatings, molded articles, etc.

Neoprene. A synthetic, rubber-like plastic formed by the polymerization of chloroprene.

Balanced coating. Equal weight and thickness of coating on each side of the fabric.

Tack time. The time required for an adhesive to become sticky to the touch.

Test equipment and data

Bros roller. A towed, four-wheeled, rubber-tired roller capable of carrying a load of 50 tons with tire pressure variations from 115 to 150 psi.

Load cart. A cart pulled by a two-wheeled, rubber-tired tractor and consisting of a load box, frame, and rubber-tired outrigger wheels to provide balance. A given test wheel can be mounted in the load box and the box weighted to apply the desired load on the wheel.

Coverage. One application of the test wheel of the load cart over each point in the traffic lane.

Seat. Amount mat has been pressed down into subgrade relative to its fully seated position, i.e. surface of mat level with surface of subgrade.

PART II: MATERIALS TESTED

Membranes

Description

7. The membranes that were laboratory- and field-tested are shown in figs. 1a-1d and described in the accompanying tabulation.

Designation	Description
T1	No. 8 cotton duck, balanced coating of 8-oz-per-sq-yd vinyl on each side of fabric; color, light gray; average weight, 2.2 lb per sq yd. This membrane was used for comparison and control
T12	8-oz-per-sq-yd nylon fabric, balanced coating of 16-oz-per-sq-yd neoprene on each side of fabric; color, black; average weight, 2.5 lb per sq yd
T13	8-oz-per-sq-yd nylon fabric, balanced coating of 8-oz-per-sq-yd vinyl on each side of fabric; color, brown; average weight, 1.5 lb per sq yd

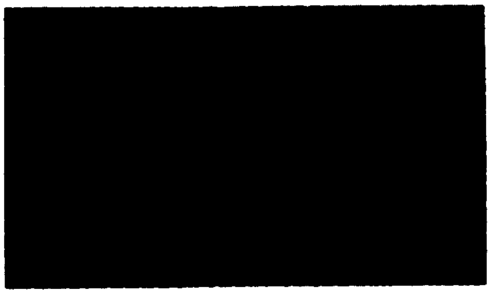

Fig. 1a. T1 membrane

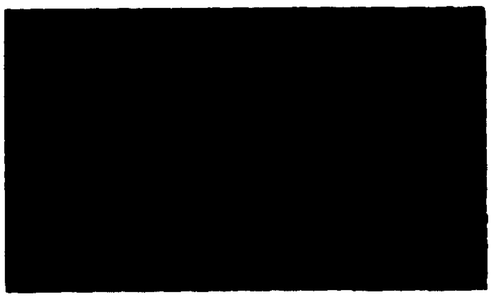

Fig. 1b. T12 membrane

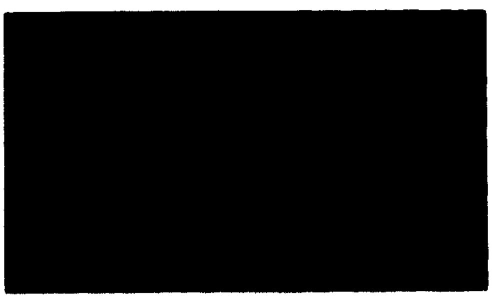

Fig. 1c. T13 membrane

Designation	Description
T14	8-oz-per-sq-yd nylon fabric, balanced coating of 20-oz-per-sq-yd neoprene on each side of fabric; color, black; average weight, 3.0 lb per sq yd. The surfaces of this membrane were embossed in an attempt to improve its skid resistance when wet

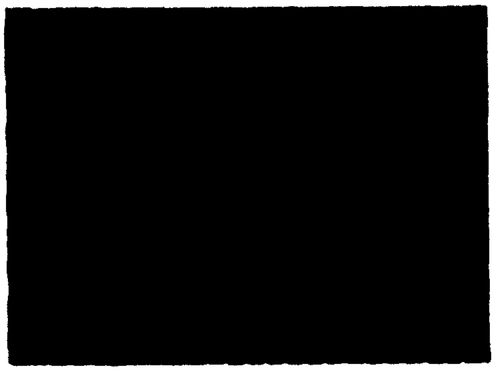

Fig. 1d. T14 membrane

Packaging

8. The membranes were received in rolls covered with heavy-duty paper and bound with three 1/2-in. steel straps (fig. 2). Each roll contained 100 lin yd of 36-in.-wide material wound on a hollow wooden core of 3-in. outside diameter and 1-in. inside diameter.

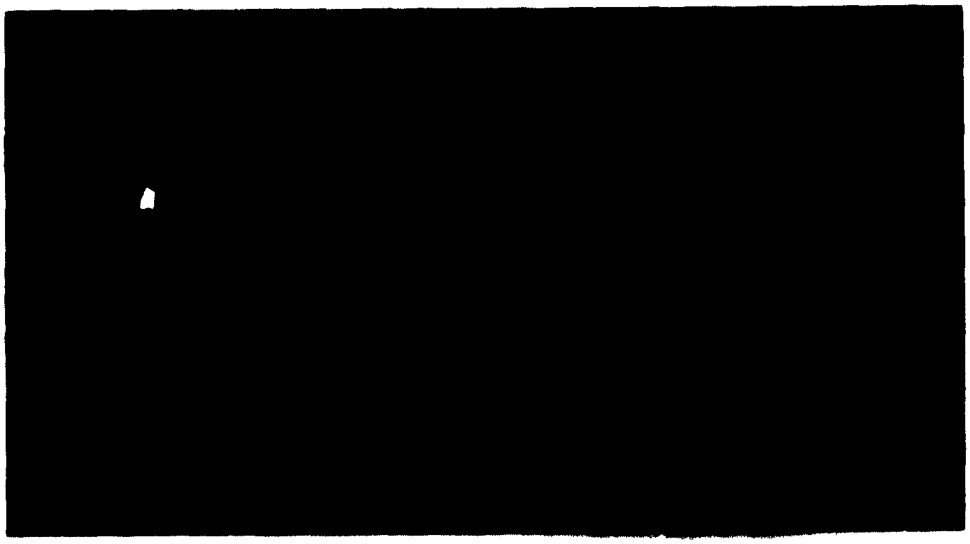

Fig. 2. Membrane roll as received from manufacturer

Sewn panels

9. In normal field operations, adhesive lap joints are used to bond runs of membrane. However, during the construction or forming of adhesive joints, foreign matter such as grass, particles of soil, and dust often

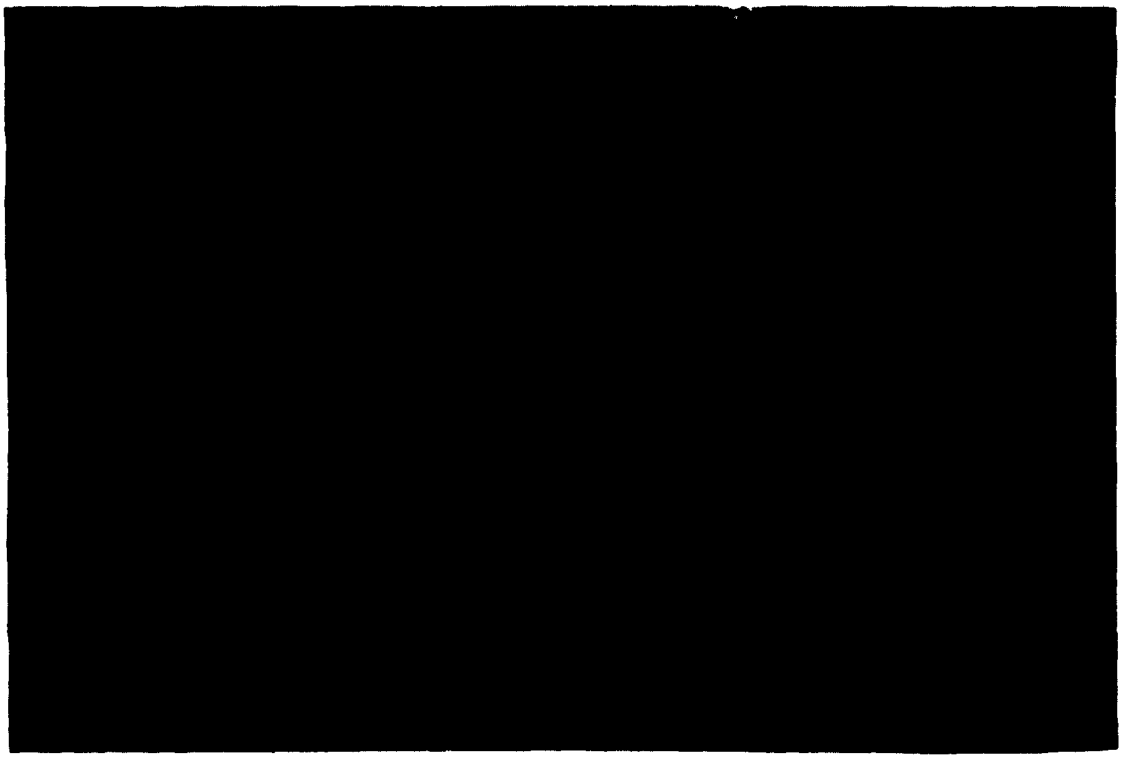

Fig. 3. Sewn membrane panel and cover

adheres to the membrane surface, necessitating considerable effort to maintain clean joints while adhesive is applied. To alleviate this construction problem, increase the membrane placement rate, decrease the number of adhesive lap joints, and decrease the quantity of membrane materials required (by reducing overlap), a test panel was designed in which the membrane runs were sewn together as shown in fig. 3. The diaper-shaped cover beneath the sewn panel was also devised for storing the panel and to facilitate rapid handling.

Adhesives

10. Since runs of membrane are usually bonded together by means of an adhesive, liquid adhesives designed for field application were evaluated. This type of adhesive is readily applied, and air-drying removes the carrier solvent for the development of bond strength. Eleven adhesives were laboratory-tested, and the most promising ones were selected for further field investigation. These adhesives were received at the Waterways

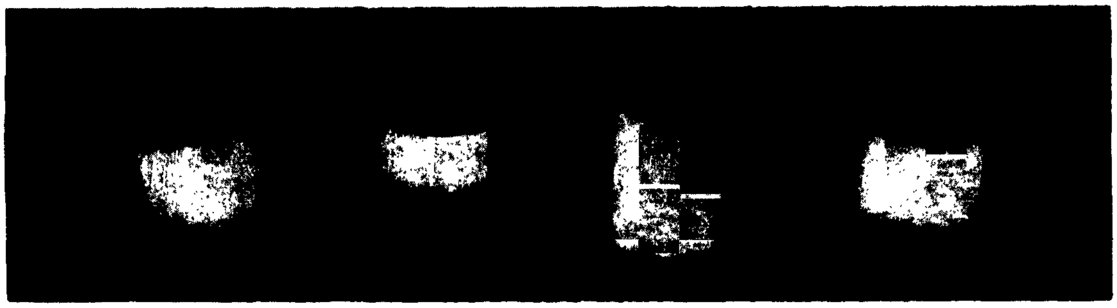

Fig. 4. 5-gal containers of adhesives

Experiment Station (WES) in 5-gal steel containers (fig. 4) weighing approximately 40 lb each.

Landing Mats

M8 mat

11. The M8 steel landing mat used in both laboratory and field tests was standard 10-gage mat formed from 0.134-in.-thick mild steel sheets in accordance with Military Specification MIL-M-59B.* This mat is shown in fig. 5, and is detailed in Corps of Engineers drawing M7613-1, which is on file at WES. The M8 is the present standard steel mat for aircraft with single-wheel loads up to 50,000 lb and 200-psi tire inflation pressure.

M9 mat

12. The M9 aluminum landing mat, which was used only in laboratory tests, was standard mat formed from 0.156-in.-thick aluminum alloy in accordance with Military Specification MIL-M-59B.** This mat is shown in fig. 6, and is detailed in Corps of Engineers drawing M8006-1, which is on file at WES. The M9 is the present standard aluminum mat for aircraft with single-wheel loads up to 50,000 lb and 200-psi tire inflation pressure.

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* The M8 mat used in this investigation was produced prior to approval of Military Specification MIL-M-59C, which specifies that nominal sheet thickness for this mat shall be 0.140 in.

** The M9 mat used in this investigation was produced prior to approval of Military Specification MIL-M-59C, which specifies that nominal sheet thickness for this mat shall be 0.160 in.

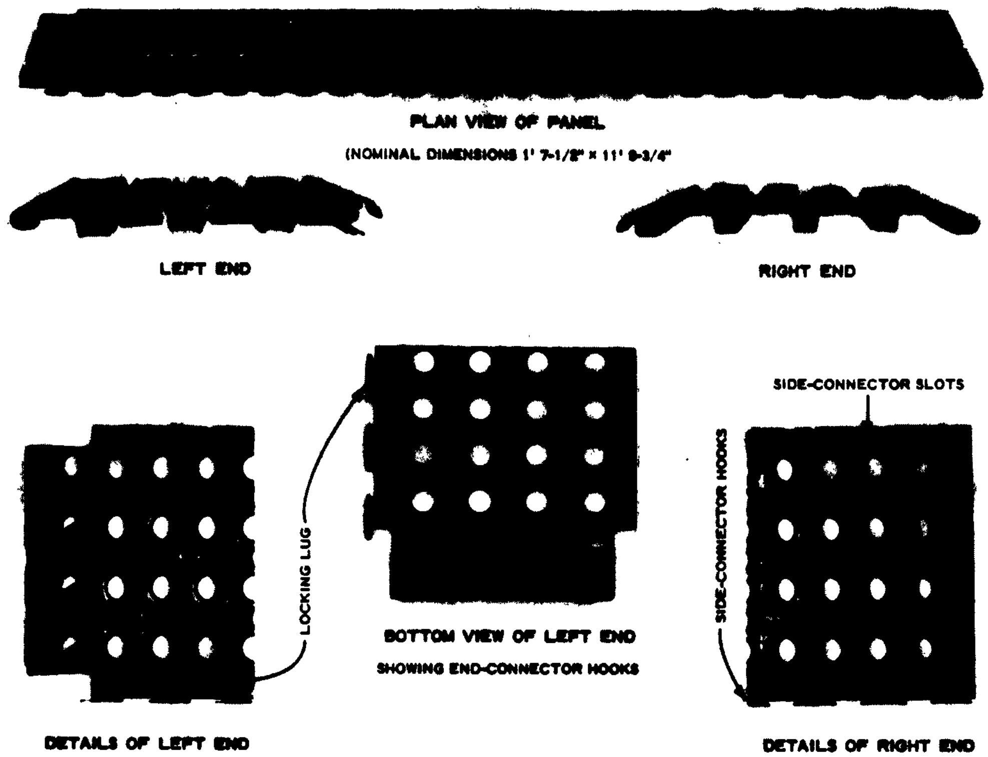

Fig. 5. Airplane landing mat, steel, pierced type, M8

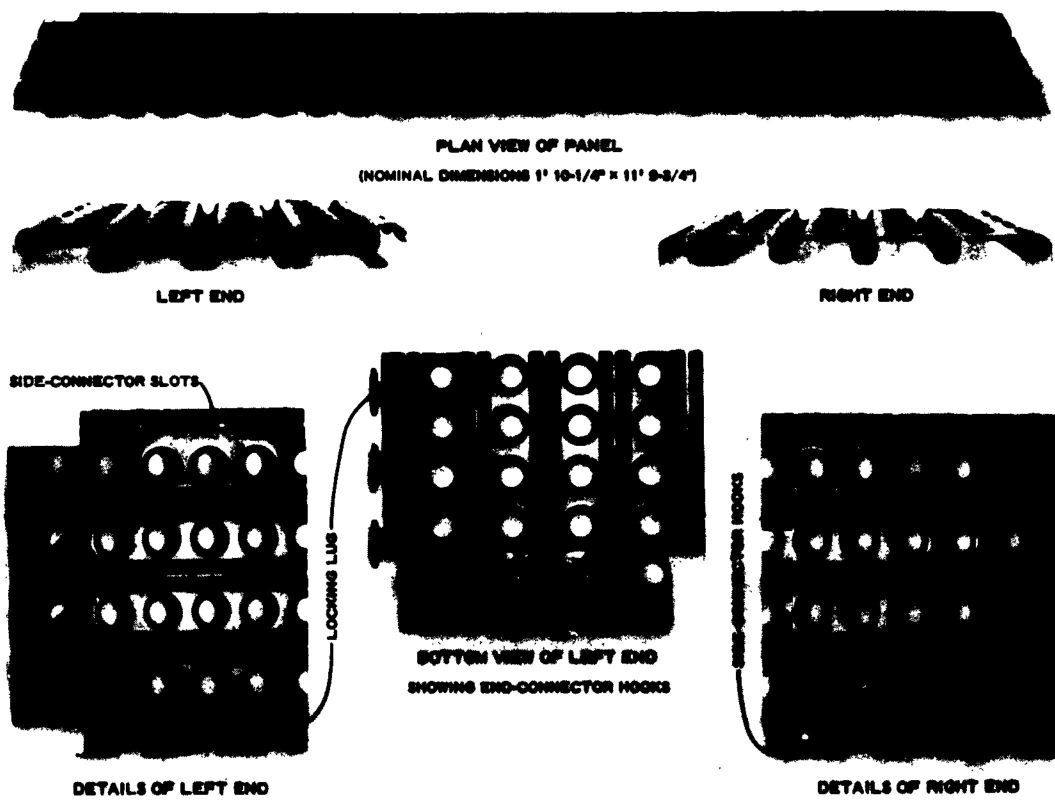

Fig. 6. Airplane landing mat, aluminum, pierced type, M9

PART III: LABORATORY TESTS AND RESULTS

Membranes

13. Laboratory tests were conducted to determine the physical characteristics of each membrane material. The tests were conducted in accordance with the methods of Federal Specification CCC-T-191b wherever applicable. However, it was also necessary to improvise and develop other test methods, in order that characteristics pertinent to project requirements could be determined.

Federal Specification tests

14. The following laboratory tests were conducted according to the methods specified:

a. Weight of Cloth; Small Specimen Method; Method 5041.

b. Strength and Elongation, Breaking of Woven Cloth; Cut Strip Method; Method 5102. This test was conducted in accordance with the Federal Specification except that the jaw-separation speed was 2 in. per min.

c. Strength of Cloth, Tearing; Tongue Method; Method 5134.

d. Water Resistance of Cloth; Water Permeability, Hydrostatic Pressure Method; Method 5516.

e. Weathering Resistance of Cloth; Accelerated Weathering Method; Method 5804.

f. Temperature, High, Effect on Cloth Blocking; Method 5872. This test was conducted in accordance with the Federal Specification except that the test specimen was heated for 2 hr at 180 F.

g. Temperature, Low, Effect on Coated Cloth; Method 5874. This test was conducted in accordance with the Federal Specification except that the test specimen was exposed for 4 hr at -40 F.

h. Fire Resistance of Cloth; Vertical; Method 5902. This test method was used to evaluate the neoprene-coated nylon membranes.

i. Burning Rate of Cloth; 30° Angle; Method 5910. This test method was used to evaluate the T13 vinyl-coated nylon membrane.

Tests developed at WES

15. To determine project requirements concerning jet-fuel resistance, heat resistance, elongation of membrane placed under landing mat, and

watertightness of joints, the following tests were devised and conducted.

a. Jet-engine fuel resistance. Membranes were immersed in jet-engine fuel (MIL-F-5624C) for 24 hr and then tested for loss of tensile strength and elongation using Method 5102.

b. Heat resistance. Membranes were exposed to a temperature of 350 F for 5 min and tested for loss of tensile strength and elongation using Method 5102.

c. Membrane behavior under landing mats. The test apparatus shown in fig. 7 was devised to determine the load and elongation that the underlying membrane must be able to sustain to permit 100 percent seating of landing mats in the subgrade. The tests were conducted by bonding a 1-in.-wide strip of membrane to the bottom of a section of landing mat so that the membrane was suspended in a free span between the ribs of the mat. As shown in fig. 7, a load was applied to the membrane span by a block shaped to fit the contour of the landing mat. As stated earlier, the M8 steel landing mat was used in the laboratory tests and in later field tests; the M9 aluminum landing mat was not used in the field tests, but was used in the laboratory tests because it poses the most severe seating problem since its

Fig. 7. Laboratory apparatus for testing membrane behavior underneath landing mat

deeper stiffening ribs require greater elongation of the membrane underlay.

d. Waterproofing. Water was ponded over sewn membrane joints and adhesive-bonded joints both before and after traffic to determine the capabilities of these joints to remain watertight. The membranes were supported by wood frames placed on trestles as shown in fig. 8.

Fig. 8. Waterproofing test for sewn joint

Test results

16. The results of laboratory tests on membranes tested in this study are shown in table 1. Note that for all test conditions the tear and tensile strengths of the nylon membranes were much higher than those of the cotton duck membrane. At 75 F (i.e. the test condition for Methods 5102 and 5134) the T14 membrane possessed the highest tensile and tear strengths (476 lb per in. width and 74 lb, respectively). However, the T13 membrane was the most elastic as it elongated 43.0 percent, and its tensile-strength-versus-weight ratio of 293 was the highest.

17. The results of laboratory tests to determine membrane behavior under the M8 and M9 landing mats are illustrated in plates 1 and 2. Maximum seating loads of 552 lb (plate 1) and 614 lb (plate 2) were computed for the M8 and M9 mats, respectively. The computations were based on the cross sections of each mat, load diagrams, a 50,000-lb single-wheel load, and 200-psi tire inflation pressure. Section A-A in plates 1 and 2 illustrates the cross section of each landing mat. The construction of the load diagrams was based on the following data and assumptions:

a. Single-wheel load of 50,000 lb

b. Tire size, 56.00-16, 32 ply, with an outside-to-outside

sidewall distance of 13.2 in. at an inflation pressure of 200 psi

c. Contact area of tire of 266 sq in.

d. Contact pressure of tire of 188 psi

e. An assumption that the landing mats distribute the 50,000-lb single-wheel load a distance of 15 in. on each side of the tire contact area

18. Plate 1 shows that only the T13 membrane permitted 100 percent seating of the M8 mat in the subgrade at the computed maximum seating load of 552 lb. At this load, the T12 membrane permitted 88 percent seating, and the T14 membrane allowed 81 percent seating. The T1 membrane failed at a load of 345 lb after permitting 75 percent seating of the mat. It was necessary to apply a load of 760 lb to the T12 membrane to obtain 100 percent seating of the M8 mat. The T14 membrane could not be made to elongate sufficiently to permit 100 percent seating of the mat as this membrane failed at a load of 850 lb after allowing 95 percent seating of the mat.

19. Plate 2 shows that at the computed maximum seating load of 614 lb for the M9 mat, the T12 membrane permitted 93 percent seating of the M9 mat, the T13 membrane permitted 100 percent seating, and the T14 membrane permitted 95 percent seating. The T1 membrane failed at a load of 355 lb after permitting 80 percent seating of the mat. It was necessary to apply loads of 710 lb to the T12 membrane and 705 lb to the T14 membrane to cause these materials to elongate sufficiently for 100 percent seating of the M9 mat.

20. In the waterproofing tests no leakage was observed during a 24-hr period, even when used and abraded pieces of material were tested, and both sewn and adhesive-bonding methods of connecting membrane were considered satisfactory.

Adhesives

21. Initially, the development of adhesives for joining membrane runs in the field was based on an adhesive shear strength requirement of 270 psi of bond area after a curing time of 24 hr at 75 F. This requirement was considered necessary to develop the full strength of the experimental vinyl-coated No. 8 cotton duck membrane and to maintain a minimum

size adhesive lap joint. After preliminary laboratory tests were completed at WES, it became apparent that readily available commercial adhesives would not develop such strength when used with a flexible material such as membrane. Therefore, the commercial adhesives which had performed most satisfactorily in the preliminary laboratory tests at WES were selected for further testing, and the lap joint was widened to develop increased shear strength. Seven adhesives selected for further testing were vinyl based and four were neoprene based. Laboratory shear strength tests were conducted after the adhesives had been allowed to air-dry at a temperature of 75 F for 24 hr.

22. The results of these tests on the vinyl and neoprene adhesives are shown in plates 3 and 4, respectively. Vinyl adhesives SBP-1146-A, SBP-579-3A, EC-866, and L-435 possessed approximately the same adhesive shear strength after a drying time of 24 hr at 75 F. However, pertinent data supplied by the manufacturer for adhesive L-435 indicated that this adhesive has a storage life of only three months; therefore, it was not tested further in the laboratory or in the field. Test results indicated that adhesive G-580 was the most satisfactory of the neoprene adhesives tested. It and vinyl adhesives SBP-1146-A, SBP-579-3A, and EC-866 were then subjected to more comprehensive tests. Results of these tests and other pertinent data on the physical characteristics of the adhesives are shown in table 2. When all adhesives and test conditions are compared, it will be noted that neoprene adhesive G-580 developed the highest shear strength, and that adhesive SBP-579-3A was the strongest of the vinyl adhesives tested in this study.

PART IV: PREPARATION OF TEST LANES

Test Lane 1

Location and description

23. Test lane 1 was constructed under the protection of a hangar to provide the conditions necessary for accurately controlled comparative traffic tests. The lane was 200 ft long and 36 ft wide, and was divided into six test sections with an approach section at each end of the lane; each test section was 25 ft long and was surfaced with membrane (plate 5).

Construction of subgrade

24. The test plan specified a subgrade processed to a depth of 30 in., with a uniform in-place CBR of approximately 40 in the top 6 in. and a minimum CBR of about 25 in the bottom 24 in. (plate 5, section A-A). The test area was excavated to a depth of 30 in. below the final grade and was then backfilled with five 6-in.-thick (after compaction) lifts of a lean clay (CL) having an average liquid limit of 34 and an average plasticity index of 12 (plate 6). Laboratory compaction and CBR data are shown in plate 7. CBR, water-content, and density tests were made during construction to ensure that the desired strengths were obtained.

Membrane placement

25. Prior to placement of membrane on the test lane, a ditch was constructed, by a ditch-digging machine, along the sides and at the ends of the lane. All membranes were placed by hand, and were extended into the ditch for a depth of 24 in. and anchored in place by backfilling the ditch.

26. Adhesive-bonded membrane sections. Test sections 1, 3, and 5 (see plate 5) were constructed by placing precut runs of membrane parallel to the center line of the test lane and allowing the runs to overlap 9 in. The 9-in. adhesive lap joint was based on the results of previous service tests at Eglin Air Force Base, Florida.* The seams at the overlap were sealed and bonded with adhesive applied with a brush to both the underlying

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* Headquarters Air Proving Ground Command, Eglin Air Force Base, Florida, Combined Final Report on Project Nos. APG/CSC/119-A-1 and APG/CSC/244-A, Operational Suitability Test of M-8 Landing Mat, Comparative and Operational Suitability Test of Waterproofing and Dustproofing Membranes (29 November 1954).

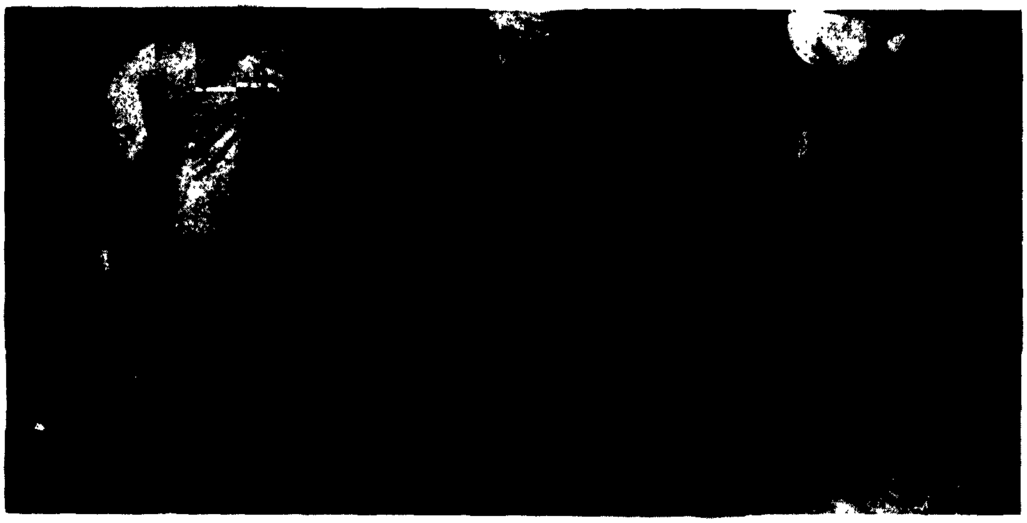

Fig. 9. Application of liquid adhesive to form membrane lap joint

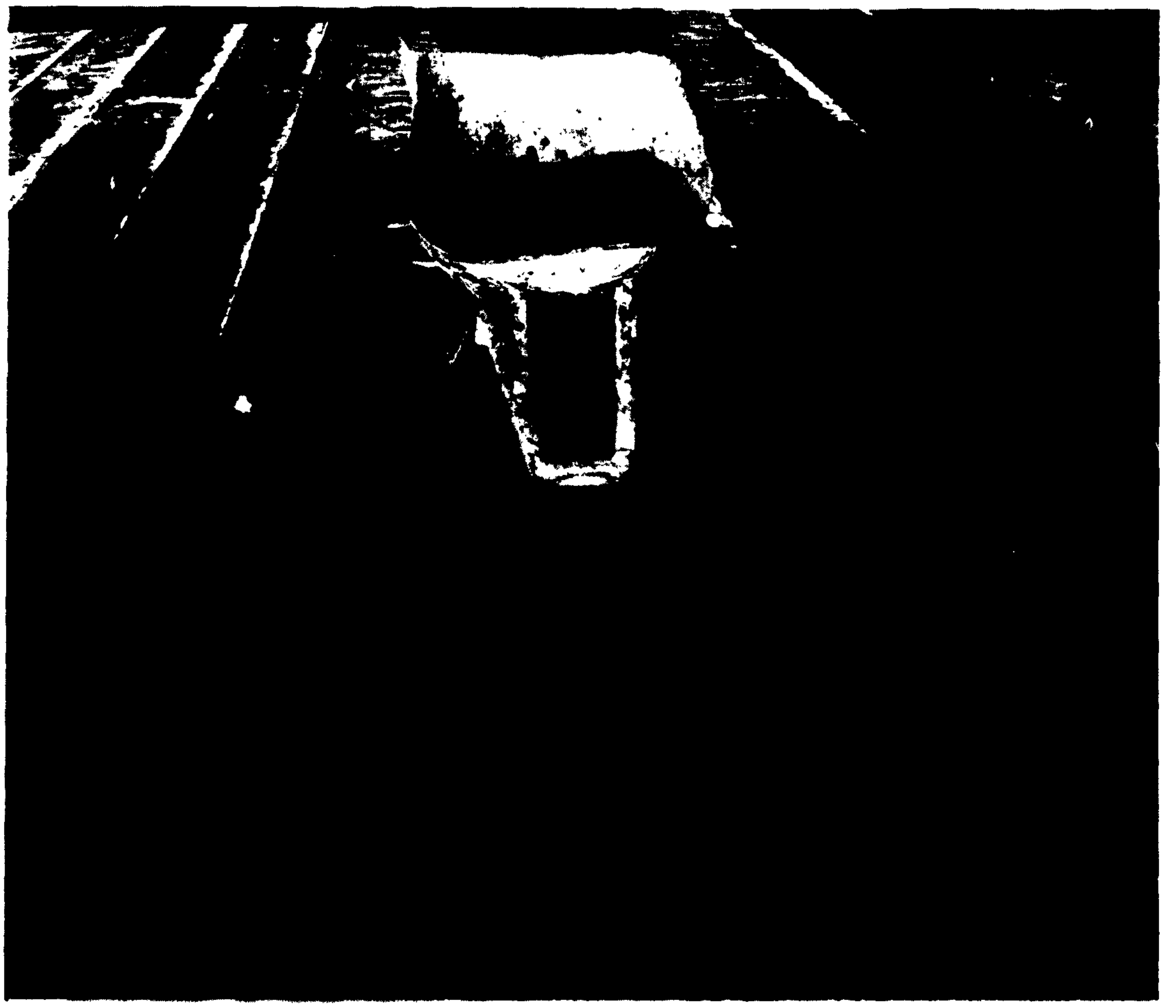

Fig. 10. Application of pressure to adhesive lap joint to ensure proper sealing

and overlapping edges of the membranes (fig. 9). Only after the adhesive became tacky were the edges placed in contact; pressure was then applied at the seams with a loaded wheelbarrow (fig. 10).

a. Section 1. Section 1 was surfaced with the T1 membrane, which was placed rapidly and produced a relatively wrinkle-free surface. Adhesive EC-866 was used for sealing and bonding the membrane joints; it required approximately 15 to 20 min to become tacky and approximately 1 hr to develop sufficient bond strength to prevent movement of the runs of membrane. The adhesive was brushed satisfactorily on the membrane surface and provided adequately sealed joints. The appearance of the completed section is shown in photograph 1.

b. Section 3. The T13 membrane was used as surfacing for section 3. This membrane was not placed as rapidly as that in section 1 because it puckered at the selvage (see photograph 2). In the construction of the adhesive lap joints, it was noted that the rubber tire of the wheelbarrow pushed a great number of puckers out of the joints into the middle of the membrane runs each time the joints were rolled. Therefore, additional rolling of the joints was performed in order to remove as many puckers as possible; nevertheless, a small number remained (photograph 3). This surface condition did not prevent joint construction, but required additional labor effort to complete the section. Adhesive SBP-579-3A, which was used to seal the joints, was a thick paste and required a thinner before it could be satisfactorily brushed on the membrane surface. The adhesive required approximately 10 to 15 min to become tacky and approximately 30 min to develop sufficient bond strength to prevent movement of the runs of membrane.

c. Section 5. The T12 membrane was used to surface section 5. When this material was removed from the roll, its surface did not appear puckered or wrinkled; however, when it was allowed to relax on a flat surface puckering became noticeable (photograph 4). In spite of this surface condition, satisfactory adhesive joints were constructed with adhesive G-580, but additional labor effort and rolling of the joints were required as described above for section 3. The appearance of the completed section is illustrated in photograph 5.

27. Sewn membrane sections. Test sections 2, 4, and 6 were surfaced with sewn panels of the T1, T13, and T12 membranes, respectively. Each panel was 42 ft wide and 26 ft long and was constructed of membrane runs sewn together with a 1-1/4-in. single-lap, double-stitched joint. To surface these sections, the sewn membranes were unfolded first across the test lane and then along the lane as shown in figs. 11 and 12. To smooth the

Fig. 11. Sewn membrane panel being unfolded across the test lane

Fig. 12. Sewn membrane panel being unfolded along the test lane

surface and thereby remove as many wrinkles as possible, the panels were also stretched and pulled as shown in fig. 13. The membrane runs of each sewn section were placed parallel to the center line of the test lane.

28. Connecting test sections. In order to obtain a continuous surfacing over the test lane, it was necessary to connect adjacent test sections (plate 5). The ends of sections 1, 2, 3, and 4 were joined with 9-in. lap joints and adhesive SBP-579-3A which was applied with a brush

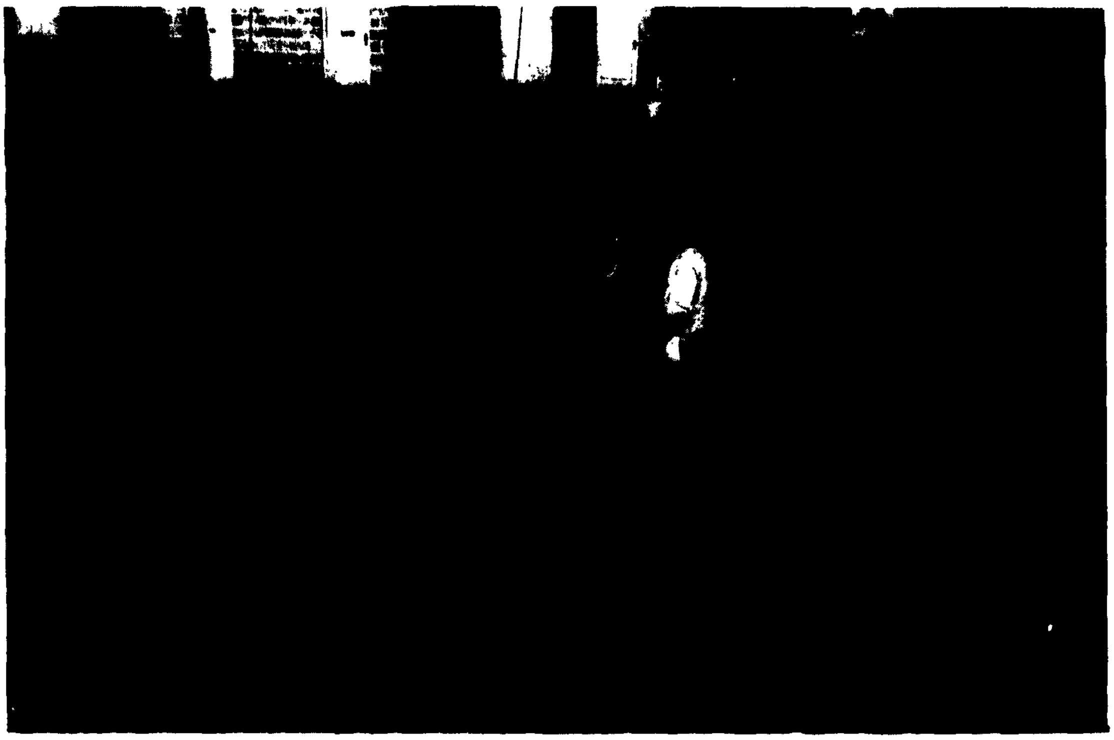

Fig. 13. Sewn membrane panel being stretched over a test section

to both the underlying and overlapping edges of the membranes. Sections 5 and 6 were joined in the same manner except that adhesive G-580 was used for sealing the joints. To join sections 4 and 5, a run of the T13 membrane was sewed across the end of the T12 panel to allow similar material to be joined by adhesive SBP-579-3A, and thereby eliminate the problem of joining a vinyl-coated membrane to a neoprene-coated membrane.

29. Membrane placing rate. The average membrane placing rate was 188 sq ft per man-hour for adhesive-constructed sections and 1720 sq ft per man-hour for the sewn membrane sections.

Test Lane 2

Location and description

30. After completion of all tests on lane 1, all membranes were removed and the same area was utilized for test lane 2. Membrane and M8 steel mat were used to surface three of the seven test sections in lane 2 to a width of 36 ft (plate 8); only membrane was used on the four remaining sections.

Preparation of subgrade

31. The top 6 in. of the lean clay subgrade was "pulvimixed" and water was added until the water content was approximately 12 percent. The subgrade was then compacted with a Bros roller to provide an in-place CBR in the top 6-in. layer of 35 to 40. The surface of the subgrade was then graded to provide a 2 percent transverse slope (fig. 14). After anchor

Fig. 14. Motorgrader preparing test lane 2

ditches were constructed along the sides and ends of the lane, membranes were extended into the ditches and anchored by backfilling. Then a drainage ditch was constructed along the low side of the lane so that water applied to the lane would drain off each section. Test sections to be surfaced with both mat and membranes were mulched to a depth of 2 in. to ensure that only the underlying membranes would resist seating of the landing mat in the subgrade.

Membrane and mat placement

32. Since the sewn membrane panels performed satisfactorily in traffic tests conducted on lane 1 and had been placed about nine times faster than adhesive-bonded panels, it was decided to use sewn panels on all test sections of lane 2. They were placed in the same manner as described in paragraph 27. Test sections A, B, and C were surfaced with sewn panels of T1, T13, and T12 membranes, respectively, and overlaid with M8 steel mat;

test sections D, E, F, and G were surfaced only with sewn panels of T14, T12, T13, and T1, respectively. (The puckering at the selvage which had been noted in the T12 and T13 membranes was also present in the T14 membrane.) A continuous membrane surfacing was provided by connecting adjacent panels with adhesive (overlap 9 in.). The membranes in sections A and B were joined with adhesive EC-866, those in sections B, C, D, E, and F with adhesive G-580, and those in sections F and G with adhesive SBP-1146-A. In order to join vinyl-coated membrane to neoprene-coated membrane (joints between sections B and C and E and F), strips of the neoprene-coated T12 membrane were sewn across the ends of the vinyl-coated T13 membrane; neoprene adhesive G-580 was then used to bond the panels. The completed membrane surfaces of sections A, B, and C prior to placement of mat are shown in photographs 6 to 8, inclusive; section D, surfaced with T14 membrane, is shown in photograph 9.

33. Broken bundles of M8 mat were placed along one side of test lane 2; mat panels were then carried by hand and placed in position by a crew of six laborers under the direction of a foreman. Placement of the mat was started on section C, and a view of this section after completion is shown in photograph 10. The appearance of section C is representative of that of mat-surfaced sections A and B also.

Placing rates

34. The average placing rate for the sewn membrane panels was 1600 sq ft per man-hour; the average placing rate for the M8 mat was 350 sq ft per man-hour. The combination of mat and membrane was placed at an average rate of 287 sq ft per man-hour.

PART V: COMPARATIVE TRAFFIC TESTS

Procedure anc Equipment

35. All test items (membranes and steel mat) were subjected to accelerated traffic in lanes 11 ft wide along the center line of the test sections, as shown in plates 5 and 8. Traffic was applied by a large, single airplane wheel mounted in the load box of a test load cart (fig. 15). A 56.00-16, 32-PR, nylon cord tire was mounted on the wheel and

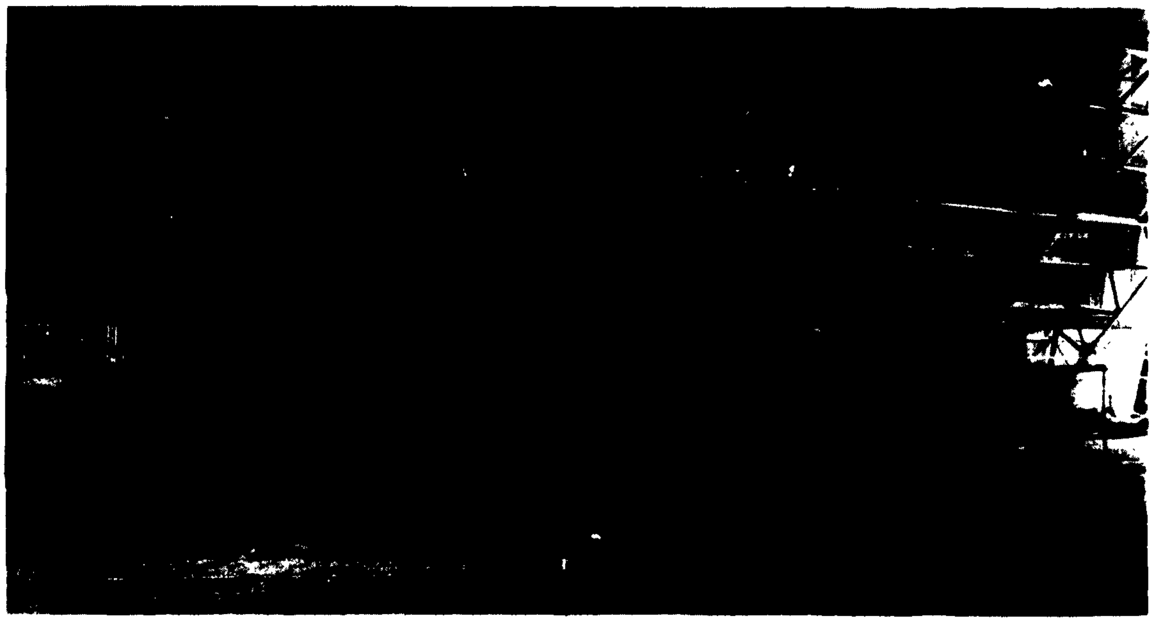

Fig. 15. Traffic test load cart

inflated to 200 psi; the load box was weighted to apply a load of 50,000 lb.

36. In application of traffic, the load cart was pulled forward along the length of the test lane and then pushed backward along the same path. On each succeeding forward trip, the cart was shifted laterally a distance equal to the width of the load-wheel tire print until the entire traffic lane had been traversed. Thus, two complete coverages were made each time the load wheel crossed the width of the traffic lane.

37. Prior to the start of traffic on lane 2, water was applied to the test sections to determine the ability of the membranes to waterproof the subgrade. A rainfall intensity of 1 in. occurring over a period of

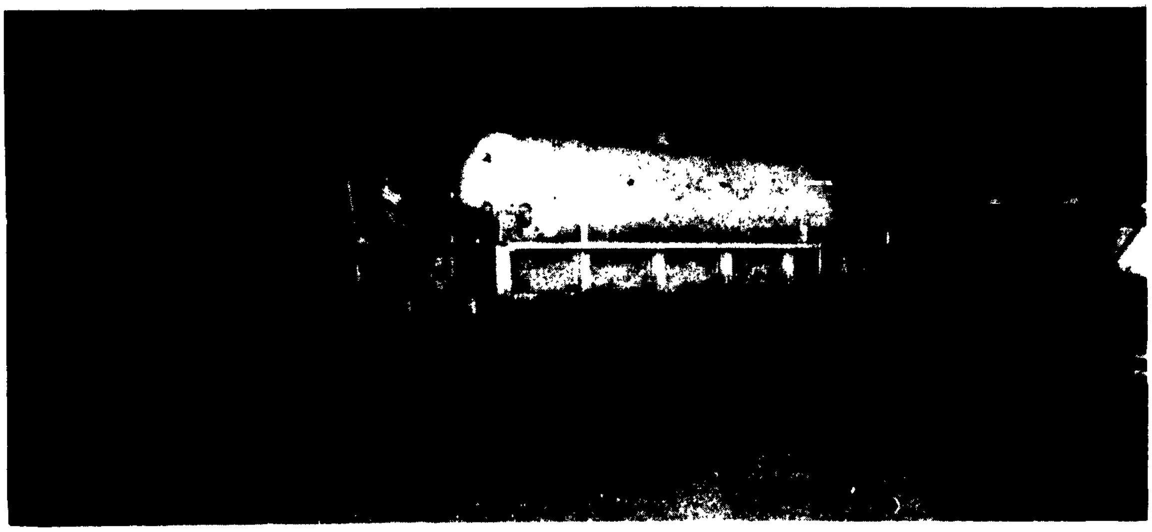

Fig. 16. Simulation of rainfall on lane 2

one hour was chosen as a representative storm; Weather Bureau records indicated that such a storm would occur in the Vicksburg area about once every two years. From the dimensions of the test lane, the total volume of water for a 1-in. rainfall was computed, and this quantity was applied to the lane over a period of one hour by means of spray bars attached to a water truck (fig. 16). To ensure thorough testing of the membranes, test lane 2 was sprayed both before traffic and after 350 coverages (middle of traffic period).

Types of Data Obtained

38. Water-content, density, and in-place CBR determinations of the subgrade were made before, during, and after traffic tests on lanes 1 and 2 (see tables 3 and 4). Level readings (cross sections) were taken before and after traffic on test lane 1 to measure permanent deformation of the sections and to indicate the degree of roughness (plates 9-14). Visual observations of the behavior of the surfacing materials and subgrade, and pertinent factors recorded throughout the traffic periods were supplemented by photographs.

Test Results

Lane 1

39. Section 1. This section, which was surfaced with the T1

membrane, was used as the control or standard with which other sections surfaced with adhesive-bonded membranes were compared. Photograph 11 illustrates the smooth surface appearance of the section before traffic. As traffic was applied, it was observed that there was a tendency for the membrane to stretch and become slack; because of this, a slight wrinkle formed in the material in front of the load wheel as it passed over the section. However, traffic did not produce any appreciable detrimental effects on this membrane. Adhesive EC-866 used for sealing the joints was satisfactory except in a small area which became unsealed at 40 coverages (fig. 17); this was a result of failure to clean the membrane surfaces properly at the time adhesive was applied. The affected area was cleaned and resealed with adhesive EC-866 which provided adequate bond for the duration of the traffic tests. After 350 coverages, traffic was discontinued as there were no indications of membrane deterioration or subgrade failure (photograph 12). As shown in table 3, the CBR of the section varied from 42 at the start of traffic to a high of 60 after 174 coverages; the CBR at the end of the test

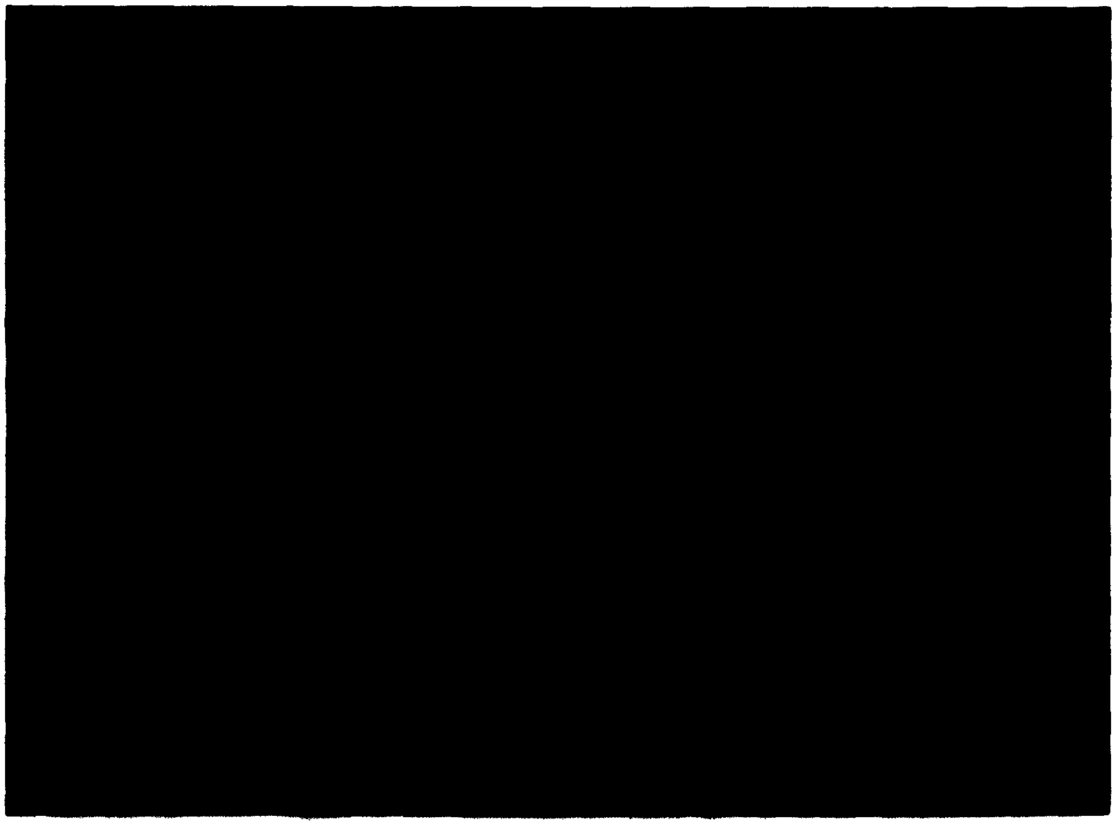

Fig. 17. Unsealed area in section 1, lane 1, after 40 coverages

was 53. The maximum change in elevation of the subgrade in the traffic lane was about 0.4 in. (plate 9).

40. Section 2. A sewn section of the T1 membrane was used to surface this section. This section was used as the control or standard with which the performance of other sewn experimental membrane sections were compared. The before-traffic appearance of the section is shown in photograph 13. As traffic was applied to the section, it was observed that the membrane adhered closely to the surface of the subgrade and did not wrinkle or roll in front of the load wheel. Traffic of the load cart did not produce any failures in the joints or the material; photograph 14 shows the surface appearance of the section after 350 coverages. The CBR of this section varied from 50 to 55 during the traffic testing period (table 3). The maximum change in subgrade elevation was about 0.4 in. (plate 10).

41. Section 3. The T13 membrane used to surface this section was sealed with adhesive SBP-579-3A. The puckered appearance of the surface of this section before traffic tests is shown in photograph 15. As traffic was applied, a wrinkle or roll approximately 1 in. high formed in front of the load wheel as it passed over the section; however, the riding surface remained smooth throughout the period of traffic. After 350 coverages (photograph 16), adhesive lap joints were beginning to work loose, especially those joints which had not been completely cleaned or had been wrinkled when constructed. Since some joints had become unsealed at approximately 350 coverages, it was assumed that the section would no longer be operational unless these joints were cleaned and resealed. The CBR of section 3 varied from 41 to 56 during traffic (table 3). The maximum change in subgrade elevation was 0.4 in. (plate 11).

42. Section 4. A sewn section of the T13 membrane was placed on section 4. Photograph 17 shows the surfaced section before the start of traffic. As traffic was applied, it was observed that a roll or wrinkle of membrane approximately 2 in. high formed in front of the load wheel as it traversed the section. However, the riding surface remained smooth throughout the traffic period, and after 350 coverages (photograph 18), there were no indications of failures in the sewn joint, membrane, or subgrade. The CBR of the subgrade varied from 41 to 61 throughout the test

period (table 3). The maximum change in subgrade elevation was about 0.4 in. (plate 12).

43. Section 5. The T12 membrane was used to surface this section, and adhesive G-580 was used to bond each run of membrane. Photograph 19 shows the wrinkled appearance of the section before traffic. During traffic tests, it was noted that a roll or wrinkle approximately 2-1/2 in. in height formed in front of the load wheel as it passed over the section, but the riding surface remained smooth throughout the period of traffic. At 174 coverages, several of the lateral joints became unsealed (fig. 18); but

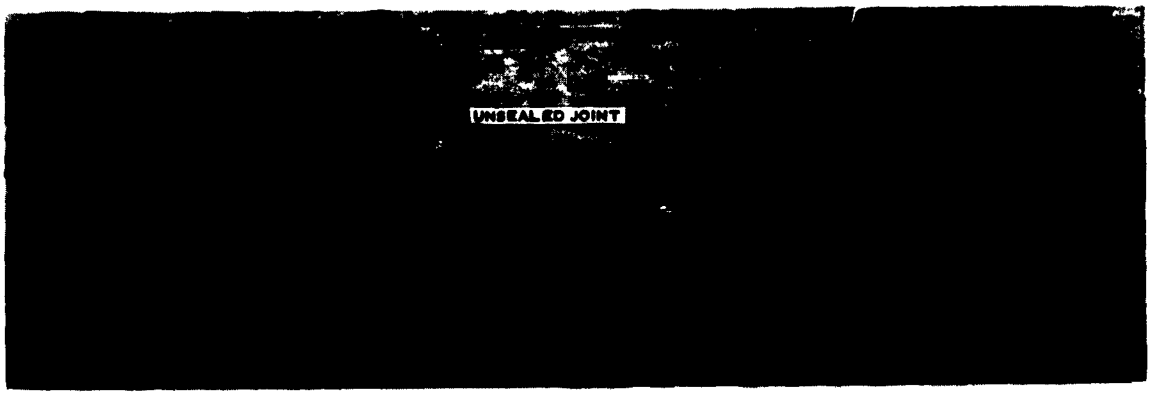

Fig. 18. Unsealed joints in section 5, lane 1, after 174 coverages

because of the small number, these joints were not cleaned and resealed. Consequently, the section was considered dustproof but not waterproof after 174 coverages. Traffic was continued to 350 coverages (photograph 20) with no further increase in the size or number of unsealed joints; also, there were no indications of membrane or subgrade failure. The CBR of the subgrade in section 5 varied from 40 to 59 during the test period (table 3). The maximum change in subgrade elevation was about 0.5 in. (plate 13).

44. Section 6. A sewn panel of the T12 membrane was used to surface section 6. Photograph 21 shows the surface appearance of the membrane before traffic. The riding surface of this section remained smooth throughout the period of traffic even though a slight wrinkle or roll of membrane approximately 1/2 in. high formed in front of the load wheel as it traversed the section. After 350 coverages, there was no evidence of failure in the membrane, sewn joint, or subgrade (photograph 22). The CBR of the subgrade in section 6 varied from 42 to 59 during the period of traffic

(table 3). The maximum change in subgrade elevation was about 0.5 in. (plate 14).

45. Summary of results. Pertinent results of tests conducted on lane 1 are as follows:

- a. All sewn membrane panels were placed approximately nine times faster than adhesive-constructed membrane panels.
- b. The adhesive-bonded T1 membrane (section 1) performed satisfactorily and was considered dustproof and waterproof throughout the period of traffic; however, adhesive-bonded T13 and T12 nylon membranes (sections 3 and 5, respectively) were considered dustproof but not waterproof because of joint failures.
- c. The sewn membrane panels (sections 2, 4, and 6) were considered dustproof and waterproof throughout the period of traffic.
- d. The puckering or wrinkling of the nylon membranes at the selvage prevented rapid construction of satisfactory adhesive joints.
- e. All membranes had sufficient strength to resist the abrasive action of accelerated traffic with the 50,000-lb single-wheel load at a tire inflation pressure of 200 psi for 350 coverages.
- f. The lean clay subgrade processed to give an in-place CBR of 40 in the top 6 in. satisfactorily supported the 50,000-lb single-wheel load for 350 coverages.

Lane 2

46. Section A. A sewn panel of the T1 membrane overlaid with M8 steel landing mat was used to surface this section. Prior to the start of traffic, 16 coverages of a Bros roller with a load of 75,000 lb and 100-psi tire inflation pressure were applied to the section to seat the mat in the subgrade. After 16 coverages of this roller, measurements revealed that the landing mat was approximately 65 percent seated. Apparently the mat embedded in the pulvimixed subgrade without difficulty under load; however, after the Bros roller was removed, the mat would spring back toward its original position. This rebounding was caused by uneven seating of the mat panels which seated easier in the center than at the ends, and by the underlying membrane which attempted to return to its original position. As the first coverages of test traffic were placed on the section, the mat panels flexed and a slight buckling of mat developed in front of the load wheel; however, the buckling dissipated before it reached the sides of the

test lane and the end of the test section. After 20 coverages, the buckling in front of the load wheel was very slight, and measurements indicated that the mat was approximately 70 percent seated. After 350 coverages, the riding surface of the section remained smooth and relatively unaffected, as shown in photograph 23. Slight circular indentations which were noted on the surface of the membrane were caused by the tubular holes in the mat. No membrane punctures were found, and both sewn and adhesive joints remained intact. Additional water was added to the lane at this time as described in paragraph 37, and traffic was continued. At 360 coverages, several small holes appeared in the membranes as a result of the cutting action of the tubular holes of the mat (photograph 24), but the holes did not enlarge rapidly. Small breaks were observed in several mat panels in the traffic lane at 500 coverages (fig. 19), and a small membrane failure had

Fig. 19. Small break in landing mat after 500 coverages, section A, lane 2

occurred near an end joint of the mat (photograph 24). The membrane failure was repaired, damaged mat panels were replaced, and traffic was continued. After 700 coverages, the riding surface of the section was smooth, even though end curl of the overlapping panels amounted to approximately 3/4 in. (photograph 25). Photograph 26 shows typical breaks in the mat after 700 coverages. (The soil on the mat surface was carried onto the test section by the load wheel from the soil bumper which was constructed

at the end of the test lane for safety purposes.) After the mat panels were removed from the section, numerous small cuts were found in the membrane; these had been caused by the rolled edge of the mat near the panel end joints (photograph 27). Sewn and adhesive membrane joints remained in excellent condition, although the thread of the sewn joints had been severely scuffed and abraded by the flexing of the landing mat. After 700 coverages, the mat in the traffic lane was approximately 70 percent seated.

47. Section B. This section was surfaced with the T13 membrane and M8 landing mat. Sixteen coverages of the Bros roller with a load of 75,000 lb and 100-psi tire pressure were applied to the section to seat the mat in the subgrade. Measurements revealed that the mat was approximately 25 percent seated before traffic tests were begun. As the test cart load wheel moved across the unseated mat, the panels deflected considerably, causing a slight roll to form immediately in front of the wheel. The mat would embed in the pulvimixed subgrade without difficulty while the load wheel was on the section; however, when it was removed, the mat would spring back approximately to its original position. No appreciable panel end curl or breaks in the mat had developed in the section after 350 coverages (photograph 28); however, the transition joint between sections B and C, which had been constructed by sewing a 36-in.-wide strip of T12 membrane over the T13, had failed (photograph 29). Apparently, as the mat was forced into the subgrade by the load wheel, the membrane was elongated about the ribs of the mat and overstressed, causing failure of the sewn joint. The mat panels were removed from section B, and the membrane was inspected. An area of the subgrade approximately 22 in. wide and 18 ft long was exposed by failure of the sewn joint (photograph 30) which permitted 100 percent seating of the mat in the failed-joint area. Before additional water and traffic were applied to the lane, the failure was repaired with T13 membrane and adhesive SBP-1146-A. (This failure of the transition joint between sections B and C was not considered in the evaluation of the joints or of the membranes of these sections, because the method of sewing the strip of T12 membrane onto the T13 membrane panel was an expedient for connecting the vinyl-coated nylon section to the neoprene-coated nylon section. Such a sewn joint would not be required or used in normal field operations.)

48. After resumption of traffic, it was noted that small breaks had

developed in the M8 mat after 500 coverages, and that considerable scuffing of the membrane surface by the tubular holes of the mat had occurred as the mat flexed under the test wheel. Several cuts found in the membrane surface near the panel end joints were caused by the rolled edge of the mat. Adhesive and sewn joints remained intact, even though the ribs of the mat had scuffed and abraded the threads of the sewn joints. The membrane area which had been patched after 350 coverages remained sealed. The riding surface of section B remained smooth after 700 coverages as no appreciable panel end curl or mat deformation had occurred (photograph 31). Small breaks had developed in several mat panels in the traffic lane, but were not considered failures as traffic could have continued. The surface of the membrane had sustained considerable scuffing from the tubular holes of the landing mat, and the vinyl coating had been removed from the top side of the fabric. However, since the fabric was coated on each side, water had not seeped into the subgrade. Several membrane punctures had occurred beneath the end of the rolled edge of the mat panel near the end joints. These punctures were caused by the rolled edge of the mat panel which moved back and forth across the membrane surface as the load wheel traversed the section, producing a knifelike cutting action and causing the punctures shown in photograph 32. All sewn and adhesive joints remained sealed, and measurements revealed that the mat in the traffic lane was approximately 50 percent seated.

49. Section C. The T12 membrane and the M8 mat were used to surface section C. Prior to traffic, the mat was seated in the pulvimixed subgrade by 16 coverages of the Bros roller with a load of 75,000 lb and 100-psi tire pressure. When traffic tests began, the mat was approximately 60 percent seated in the subgrade. The mat would seat fully while the load wheel was on the section, but when it was removed, the mat would spring back toward its original position. Inspection of the section after 350 coverages did not reveal any failures in the mat or membrane. All sewn and adhesive joints remained intact, and the membrane surface had received very little scuffing from the tubular holes in the mat. After 500 coverages small breaks were noted in the mat, but the riding surface of the section remained smooth and panel end curl had not developed. Even after 700 coverages, the riding surface of the section remained smooth and virtually

unaffected by the accelerated traffic (photograph 33). Generally, the membrane surfacing remained in excellent condition, but several isolated failures were noted which had occurred near mat panel end joints, as shown in photograph 34. These membrane failures were caused by the rolled edge of the mat near the end joint; the cuts averaged 1-1/2 in. in length. Photograph 34 shows that the thread of the sewn joints had sustained considerable scuffing and abrading from the ribs of the landing mat, and the tubular holes of the mat had caused slight indentations in the membrane surface, but the coating had not peeled from the fabric. Measurements indicated that the mat was approximately 80 percent seated after the completion of the traffic tests.

50. Sections D, E, and F. The T14, T12, and T13 nylon membranes were used to surface sections D, E, and F, respectively. Photographs 35, 37, and 39 show the relatively wrinkle-free surfaces of these sections prior to traffic tests. As the load wheel traversed each section, a slight roll formed immediately in front and to the sides of the wheel. Nevertheless, the riding surface of each section remained smooth, and accelerated traffic produced no failures in the membrane surfaces. The sections were inspected at 40, 176, 280, 350, 500, and 700 coverages. These inspections revealed that the membrane surfaces and joints (sewn and adhesive) were intact and waterproof. Photographs 36, 38, and 40 show the membrane surfaces of sections D, E, and F after 700 coverages. The patch shown in photograph 40 covers a hole which had been cut in the membrane surface of section F for inspection of the subgrade after 350 coverages.

51. Section G. The T1 membrane which surfaced section G presented a smooth surface appearance before traffic tests (photograph 41). Inspections at 40, 176, 280, and 500 coverages revealed that the section was waterproof and relatively unaffected by the traffic. After 700 coverages, most of the section remained intact (photograph 42); however, one small hole had developed in the membrane, as shown in fig. 20. This hole was caused by a piece of gravel which was forced through the membrane by the load wheel. In normal field or user tests, this small hole would not constitute a major failure as it could be swiftly repaired by patching.

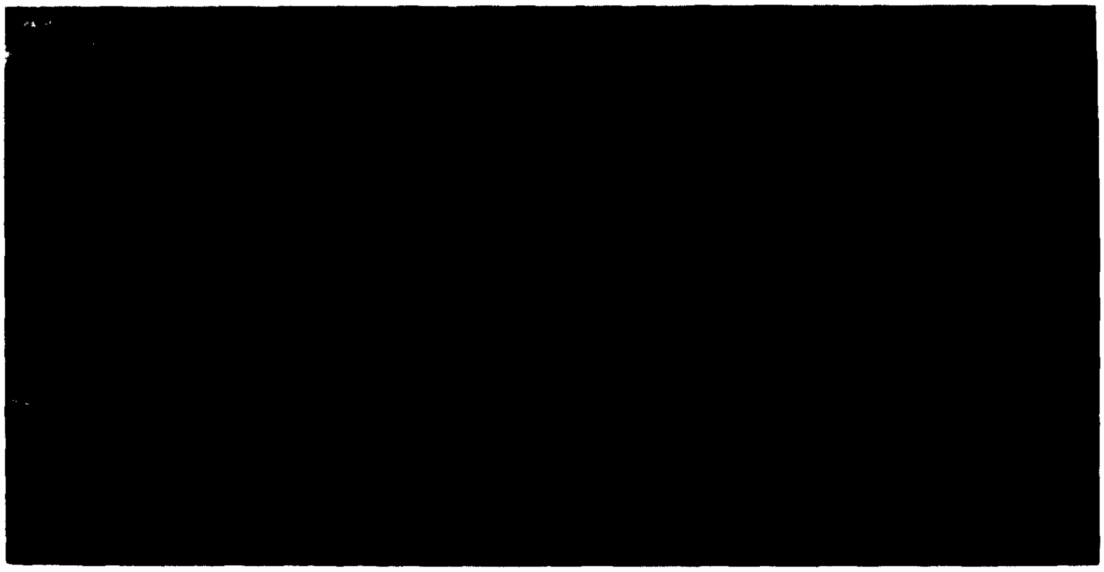

Fig. 20. Gravel puncture of T1 membrane after 700 coverages, section G, lane 2

52. Summary of results. Pertinent findings of traffic tests conducted on lane 2 are as follows.

a. Sections surfaced with landing mat and membrane panels:

(1) A dustproof and waterproof surfacing was provided by the three membranes beneath the M8 landing mat without membrane repairs for the number of coverages listed below.

Membrane	Coverages
T1, vinyl-coated No. 8 cotton duck	360
T13, vinyl-coated nylon	500
T12, neoprene-coated nylon	700

(2) Although no membrane permitted full seating of the landing mat, the T12 membrane was the most satisfactory as it allowed approximately 80 percent seating of the mat.

(3) Panel end curl and small breaks developed in the landing mat panels; however, they were not serious enough to be considered tire hazards or warrant the replacement of the mat panels.

(4) The major cause of membrane failure was the cutting of the membrane by the rolled edge of the mat near the end joint. The tubular holes of the mat cut the T1 cotton duck membrane but not the T12 and T13 nylon membranes.

(5) Sewn and adhesive joints were satisfactory throughout the period of traffic. (The transition joint between sections B and C was not considered.)

(6) Membrane failures beneath the M8 landing mat were repaired satisfactorily, and no additional failures occurred in any repaired areas during subsequent traffic.

b. Sections surfaced only with sewn membrane panels:

(1) Sewn nylon membrane panels provided a dustproof and waterproof wearing surface for the entire period of traffic.

(2) Gravel particles punctured the T1 membrane but not the nylon membranes.

(3) Both sewn and adhesive joints proved adequate throughout the traffic tests.

(4) Adhesive G-580 was adequate for bonding neoprene-coated sewn membrane panels.

(5) Adhesives EC-866 and SBP-1146-A were satisfactory for bonding vinyl-coated sewn membrane panels; however, SBP-1146-A was the best performing adhesive since it was more viscous, brushed more readily onto the membrane surface, and had much lower tack and drying times than those of EC-866.

PART VI: BLAST TESTS

53. Prior to the start of traffic on lane 2, blast tests were conducted to determine the heat resistance of the membrane materials and to evaluate the effectiveness of the membrane in dustproofing the soil subgrade. The project requirement (Appendix A) for heat resistance states that membrane should be resistant to the deteriorating effects of jet-exhaust and rocket-assist blasts with temperatures up to 350 F.

Test Aircraft and Method of Testing

54. The tests were conducted with an F-84F jet aircraft to obtain a temperature of approximately 350 F. However, it was first necessary to determine the following:

- a. The required height of the tail pipe above the test section
- b. The distance the aircraft should be placed from the test section
- c. The percentage of total engine power required to produce a temperature of 350 F

These distances and the amount of engine power were determined by trial runs which were conducted on section C where thermocouples were installed on the surface of the landing mat for recording temperatures. The thermocouples were constructed of 20-gage iron constantan wire which was covered with glass-fiber insulation. The ends of the wires were bared, crimped, and silver soldered. Thermocouples were placed on 3-ft centers along and across the traffic lane (plate 15). Lead wires for the thermocouples were carried along the ribs of the mat to the side of the lane where they were connected through a junction box to the recording instrument. A direct recorder was used to record all thermocouple temperatures while jet-engine exhaust blasts were in progress.

55. During trial runs on section C, the height of the tail pipe above the test section was varied by raising the nose gear of the aircraft with a mobile crane (fig. 21) and inserting an inclined platform beneath the gear (fig. 22). During the exhaust blast tests, the oleo strut of the nose gear was prevented from oscillating by a wood block which was attached

Fig. 21. Jet aircraft being positioned for blast tests

Fig. 22. Jet aircraft in position for blast tests

to the inner cylinder of the strut while the strut was fully extended; the aircraft was held stationary by its brakes, wood chocks, and tie-downs. From trial runs, it was determined that the nose gear should be raised

approximately 13 in. above the test section with jet engine power at 40 percent to develop the blast pattern (maximum temperature of 365 F) shown in plate 16. This pattern was subsequently reproduced on each test section beginning at section A and continuing through section G. Each test section was exposed to the exhaust blast for 5 min.

56. Since the blast pattern had been determined by thermocouples on section C, it was not necessary to install thermocouples in every section of the test lane. However, a thermocouple was attached to a rod (fig. 23)

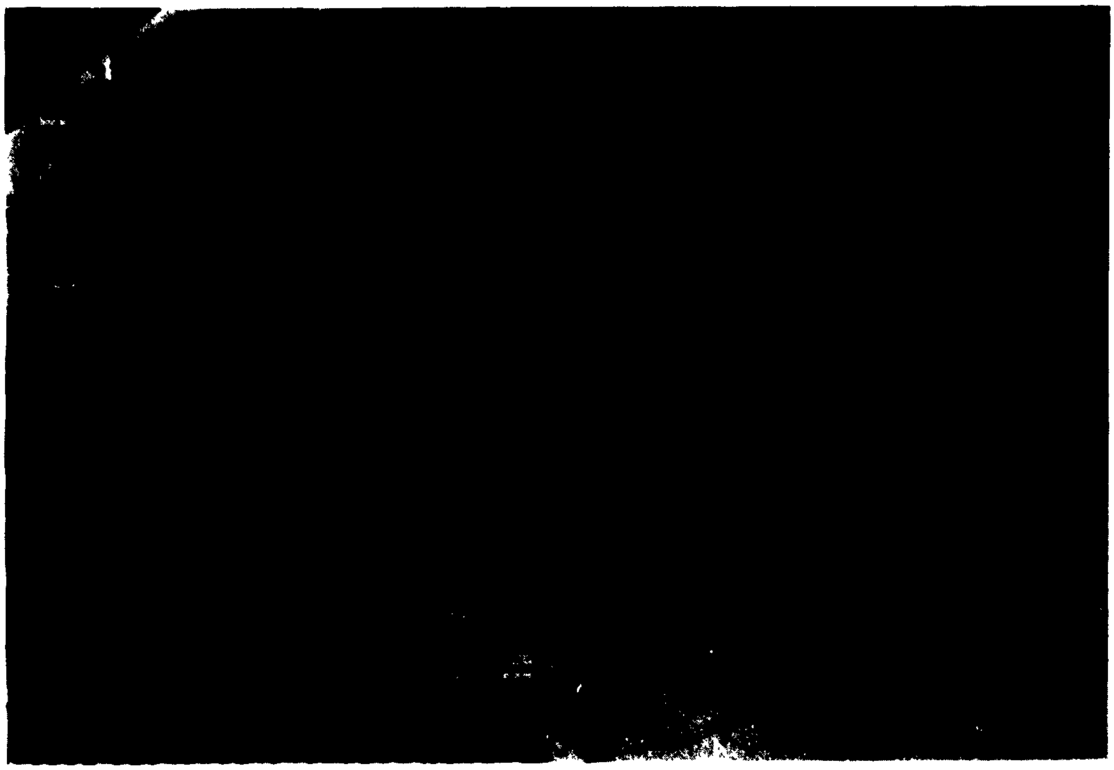

Fig. 23. Method of determining center of blast pattern

and moved along and across the test section after the aircraft reached 40 percent engine power, to ensure that the blast pattern was properly positioned on the section and to determine the "hot spot" or center of the blast pattern.

Test Results

Landing mat-membrane sections

57. The jet-exhaust blast tests conducted on sections A, B, and C,

surfaced with landing mat and membrane, produced no visible evidence of mat or membrane failure; also, there was no erosion of the subgrade nor generation of a dust cloud. Photograph 43 shows a typical landing mat-membrane surfaced test section after exposure to the jet-engine exhaust blast. No visible changes were apparent other than a slight discoloration of the paint on the landing mat surface near the center of the blast pattern.

Membrane sections

58. All membranes on sections D, E, F, and G performed essentially in the same manner, and the following discussion applies to all of these sections. The aircraft was positioned so that the blast pattern was located in the middle of the test section and traffic lane. As the blast passed over a section, a slight rippling of the membrane surface was observed; however, after approximately 2 min of the test cycle, the membrane surface flattened and smoothed out in the immediate blast area and no further rippling was observed. Photographs 44-47 show the appearance of each membrane surface after an exposure of 5 min to the jet-exhaust blast. Note that there were no indications of membrane or sewn-joint failures in any section. The small black spots visible in the photographs are where fuel leaked from the test aircraft.

Adhesive joints

59. A continuous membrane surfacing was constructed on lane 2 by joining each sewn test panel to an adjoining test panel by 9-in. single-lap adhesive joints which extended across the full width of the test lane. Each adhesive joint was exposed to the jet-exhaust blast to determine the adhesive bond strength at elevated temperatures. Information supplied by the manufacturers and obtained from laboratory tests indicated that the adhesives would perform satisfactorily for a temperature range of 300 to 350 F. To determine the safe operating range of the adhesives, the aircraft was first positioned to produce a peak temperature of approximately 200 F on each joint. An exposure to 200 F for 5 min caused failure of the joint constructed with adhesive EC-866; however, other adhesive joints remained intact. The aircraft was next positioned to produce a peak temperature of approximately 250 F, and this temperature was maintained on all unfailed joints for 5 min. This resulted in failure of the joint bonded with adhesive SBP-1146-A, but the joints bonded with adhesive G-580 were

not affected. A typical vinyl-adhesive joint failure is shown in photograph 48. In the center of the failed joint, the adhesive was charred, but near the edges of the failed joint, it was tacky. Since a temperature of 250 F for 5 min did not cause failure of joints constructed with adhesive G-580, the aircraft was positioned for a peak temperature of approximately 300 F; this temperature on these joints for 5 min caused failure. A typical neoprene-adhesive joint failure is shown in photograph 49.

60. The following discussion of the jet-engine exhaust blast tests of adhesive joints applies equally to both the vinyl- and neoprene-based adhesives, except that the vinyl adhesive failed in a range of 200 to 250 F, and the neoprene adhesive failed at an approximate temperature of 300 F. As the jet blast passed over the joint, the membrane appeared to shrink slightly, and then a small opening was forced in the joint about the center of the blast pattern. As the blast continued, this small opening enlarged and progressed across the lane for a distance of approximately 7 ft (photograph 49). Upon completion of the blast test, the joint was inspected to determine possible causes of failure. It was found that the excessive heat had caused the adhesive to become tacky, thereby destroying the bond strength. All failed adhesive joints were repaired and resealed before water and traffic were applied to the traffic lane of test lane 2.

Summary of Results of Blast Tests

61. The results of the jet-engine exhaust blast tests are summarized as follows:

- a. When used alone or beneath M8 landing mat, sewn membrane test panels provided a dustproof surfacing and prevented erosion of the subgrade by direct-impingement blasts of the jet engine.
- b. The membranes and sewn joints were resistant to the deteriorating effects of the jet aircraft blast of 365 F for a maximum of 5 min.
- c. Joints constructed with the following adhesives failed from a 5-min exposure at the temperatures indicated:

Adhesive	Temperature, °F
Vinyl adhesive, EC-866	200
Vinyl adhesive, SBP-1146-A	250
Neoprene adhesive, G-580	300

d. Contrary to claims of the manufacturers, tests indicated that no adhesive would withstand a temperature of 350 F for 5 min.

e. Neoprene-based adhesive G-580 withstood a higher temperature than the vinyl-based adhesives.

PART VII: SKID-RESISTANCE AND TIRE-WEAR TESTS

Test Equipment and Method of Testing

62. Immediately after traffic tests on lane 2 were completed, tests were conducted on that lane to determine the skid-resistance and tire-wear characteristics of each membrane surfacing. The tests were performed by towing a pneumatic-tired load cart with wheels locked over sections D, E, F, and G at a uniform speed. The load cart used in these tests (fig. 24)

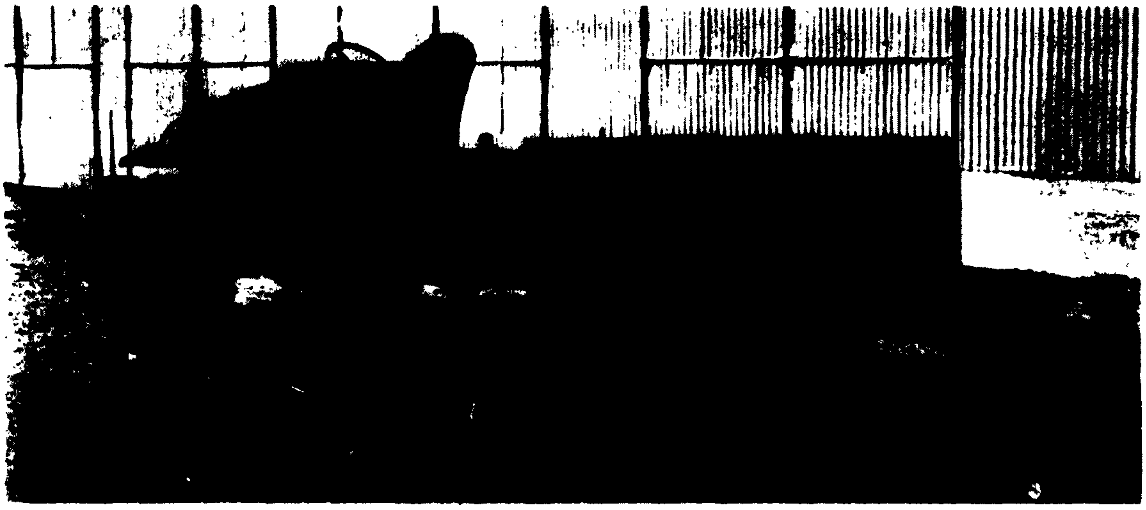

Fig. 24. Load cart used in skid-resistance and tire-wear tests

was constructed from an Athey wagon and the front end of a 2-1/2-ton, 6x6 truck. The wheels of the Athey wagon are spaced on 6-ft centers and act essentially as two single-wheel loads. For these tests, the cart was loaded to achieve 10,000 lb on each wheel, and the tires were inflated to 200 psi. Two 26.00-6.6 tires with a contact area of 53 sq in. and an average contact pressure of 188 psi were used on the load wheels. The truck section was used only for steering; a motor patrol and a D7 tractor were used to pull the load cart (fig. 25).

63. The load cart was first positioned on the test section and then both load wheels were locked to prevent rotation. The tires were skidded at a uniform speed over each membrane surface, both wet (by the method described in paragraph 37) and dry, to determine the comparative skid resistance offered by the surfaces and the tire wear resulting from skidding.

Fig. 25. Equipment used to tow load cart for skid-resistance and tire-wear tests

The tires were skidded in the middle of the membrane runs and on each type of membrane joint (adhesive and sewn). After each test, the load wheels were rotated slightly to ensure that undamaged areas of the tires were in contact with the membrane.

64. The force required to move the locked wheels of the load cart across each membrane surface was measured by a 20,000-lb-capacity electric dynamometer attached between the load cart and the motor patrol. A universal analyzer and direct-inking oscillograph were used to measure and record data. Tire wear was estimated by visual inspection.

Test Results

Skid resistance

65. Since a large force was required to initiate movement of the load cart and a smaller force to maintain movement, all oscillograms illustrated considerable fluctuations in the magnitude of forces required to move the load cart. Therefore, average values of the forces required to keep the load cart moving at a uniform rate over the membrane surfaces were determined from the oscillograms, and these values were used for the

specific purposes of the tests. The average forces which were computed are presented in table 5. These forces were divided by the total load on both wheels (20,000 lb), and the resulting ratios are shown as coefficients of friction in table 5.

66. An examination of table 5 reveals that the T14 embossed membrane with a friction coefficient of 0.56 is the best skid-resistant surface when dry, and that the T1 membrane is second best. The T13 membrane was the least effective of the dry surfaces for providing skid resistance. There was very little difference in the coefficients of friction (0.16 to 0.18) for wet membrane surfaces.

<u>Tire wear</u>

67. As shown in table 5, the degree of tire wear was negligible for all membrane surfaces, both wet and dry. Fig. 26 shows the slightly buffed surface of a tire on the load cart after a typical locked-wheel drag test.

Fig. 26. Typical tire wear caused by dragging locked wheel over membrane surfacing

68. These test methods were used to simulate aircraft operations, and it is believed that the coefficients obtained are not only conservative but that they also indicate the capabilities of the membranes to provide a braking surface for aircraft wheels. Typical aircraft braking marks, shown in photograph 50 (made at Fort Rucker, Alabama), on the T1, vinyl-coated No. 8 cotton duck membrane may be compared with those shown in photograph 51, which were caused by the WES skid-resistance test cart. Similar skid-mark patterns were produced on each membrane used in the skid-resistance tests.

PART VIII: DISCUSSION OF RESULTS

Field Test Limitations

69. The load cart used for the traffic tests is adequate for simulating aircraft wheel loads in determination of the wear, abrasion, and puncture resistance of the membrane when used alone or beneath landing mat. It does not reproduce the effects of braking action, touchdowns, or locked-wheel turns, which were found in previous investigations* to produce the most severe damage to membranes. As a supplement to the traffic tests, skid-resistance or braking-action tests were conducted with an improvised Athey wagon to determine the relative skid resistance or braking action afforded by each type of membrane surface. Even though most of the effects of aircraft operations on the materials were reproduced, the effects of touchdowns and locked-wheel turns of aircraft were not reproduced. Therefore, these test results should be confirmed by field tests under actual user conditions.

Elastomers

70. For the T1 and T13 membranes, the vinyl coatings were applied equally to both sides of the cotton duck and nylon fabrics at the rate of 8 oz per sq yd. Throughout the period of traffic tests on lane 1, there were no indications of abrasion, deterioration, or removal of the vinyl coatings from the fabrics by the load wheel. Similarly on lane 2, traffic caused no damage to the vinyl coatings of the membrane-surfaced areas. However, in the landing mat-membrane surfaced sections of lane 2, considerable scuffing and removal of the vinyl coating of the T13 membrane was caused by the abrasive action of the landing mat. The landing mat also scuffed and abraded the vinyl surface of the T1 membrane, but the removal of coating was not as pronounced as on the T13 membrane.

71. Neoprene coatings of 16 and 20 oz per sq yd were applied to each

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* Air Proving Ground Command, Eglin Air Force Base, Florida, Comparative and Operational Suitability Test of Waterproofing and Dustproofing Membrane, Project No. APG/CSC/244-A (29 November 1954).

side of the T12 and T14 nylon fabrics, respectively. In membrane-surfaced areas of test lanes 1 and 2, traffic tests did not damage or cause deterioration of the neoprene coatings of the T12 and T14 membranes. In the landing mat-membrane test area of lane 2, the T12 membrane was the only neoprene-coated membrane used as a dustproofing and waterproofing surfacing beneath the mat. During traffic tests, the T12 membrane was relatively unaffected by the abrasive action of the mat. After traffic tests, slight indentations were visible on the surface of the neoprene coating. These small scuff marks were caused by the tubular holes of the mat which buffed the membrane surface but did not remove the coating. Consequently, the results of this investigation indicate that the neoprene coating used on the T12 membrane was more resistant to the abrasive action of the landing mat than the vinyl coatings used on the T1 and T13 membranes.

Fabrics

72. The base fabric of the T1 membrane is No. 8 cotton duck. Although this fabric was the best performing of those materials tested in engineer and user tests, aircraft wheels tore the fabric on landings. Storage tests in the Panama Canal Zone* also revealed that the No. 8 cotton duck fabric deteriorated after open storage for about three years. Therefore, to improve, reduce, and/or eliminate the deficiencies of the cotton duck fabric, a nylon fabric was investigated in these tests. It was hoped that the nylon fabric would provide increased strength at decreased weight as well as increased service life and durability. A basket-weave nylon fabric was used to increase the tear strength of the membrane and thereby eliminate failures in runway touchdown areas. Laboratory tests indicated the nylon fabric to be approximately three times stronger in tear strength than the cotton duck (table 1). Field test results confirmed the laboratory results since the nylon fabric performed more satisfactorily than the cotton duck fabric as an expedient waterproofing and dustproofing medium

* U. S. Army Engineer Waterways Experiment Station, CE, Prefabricated Airfield and Road Surfacing Membranes; Torrid Zone Storageability Tests, 1954-1957, Technical Report No. 3-515, Report 2 (Vicksburg, Miss., May 1960).

under landing mat and as a wearing surface without mat. Punctures of the T1 cotton duck membrane which were caused by the landing mat enlarged slowly as traffic tests continued; however, cuts in the T13 nylon membrane did not progress under accelerated traffic tests. An inspection of test lane 2 after traffic tests were completed revealed that small quantities of gravel and slag, approximately 1/2 in. in diameter, were present on the surface of the subgrade. These materials did not puncture the nylon membranes used as wearing surfaces, but the cotton duck membrane was punctured.

Adhesives

73. The liquid adhesives used for bonding membranes in this study provided adequate joints throughout the test period. However, much more effort and time were required to construct test sections using adhesive joints than using sewn panels. Vinyl adhesive SBP-579-3A was a thick syrup and required a thinner before satisfactory application was obtained. Vinyl adhesive EC-866 was slow to become tacky and required much more time than the other adhesives for developing full bond strength. The SBP-1146-A adhesive was the best performing vinyl adhesive because of its rapid tack time and the small amount of drying time it required for development of bond strength. Neoprene adhesive G-580 also proved adequate for bonding neoprene-coated membranes. Laboratory tests indicated that all of the adhesives were satisfactory for 5 min at a temperature of 350 F. However, in field tests the adhesive joints failed when exposed for 5 min to jet-aircraft exhaust blasts at temperatures less than 350 F. In fact, the best vinyl adhesive was satisfactory at a temperature of 250 F and the neoprene adhesive was satisfactory at 300 F for 5 min. Therefore, field test results on the adhesives indicate that the laboratory test method used to determine maximum operating temperatures of adhesives did not simulate adequately the effects of the jet-aircraft exhaust blast. Before further evaluations of adhesives are undertaken, efforts should be directed toward the development of a laboratory test method which produces not only the heat but also the blast effects of jet aircraft, as these factors are most detrimental to the performance of adhesives. All adhesives were applied to

the membranes during dry conditions (i.e. no rain or moisture present). As most adhesives are adversely affected by moisture, rain precludes their application during field operations unless some type of shelter is provided.

Sewn Membrane Panels

74. The sewn membrane panels provided an expedient dustproof and waterproof surfacing. This method of providing prefabricated membrane panels increased the membrane placement rate, decreased the quantity of membrane material required (by reducing overlap), and eliminated most of the adhesive lap joints. Similar sewn panels of the T1, vinyl-coated No. 8 cotton duck membrane were service-tested by the U. S. Army Aviation Board, Fort Rucker, Alabama, under traffic of fixed-wing aircraft and helicopters* and proved satisfactory. In the Fort Rucker investigation, the ends of the panels were connected by means of adhesive-lap joints during dry conditions (i.e. no rain or moisture present). To fully exploit this type of sewn panel, additional study and investigation will be required in order to develop some type of connector or fastener that will make it feasible to eliminate the use of adhesive altogether, and thus permit uninterrupted placement of the membrane during inclement weather.

* U. S. Army Aviation Board, Report of Test, Project NR AVN 2658, Service Test of Vinyl Membrane as Airfield Surfacing Material (Fort Rucker, Ala., 4 June 1959).

PART IX: SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Results

75. The important findings of the traffic tests on the membrane-surfaced and the landing mat-membrane surfaced test lanes are as follows:

a. Sewn membrane panels were placed approximately nine times faster than adhesive-constructed membrane panels.

b. Sewn membrane panels performed satisfactorily throughout traffic tests, whereas some adhesive-constructed panels were not satisfactory because the joints became unsealed.

c. The adhesive-constructed section of T1, vinyl-coated No. 8 cotton duck membrane performed satisfactorily and was considered dustproof and waterproof throughout the period of traffic; adhesive-constructed panels of nylon membranes were considered dustproof but not waterproof because of joint failures (see 75d).

d. The puckering or wrinkling of nylon membranes at the selvage prevented rapid construction of satisfactory adhesive joints.

e. In membrane-surfaced sections only, all membranes had sufficient strength to resist the abrasive action of accelerated traffic with the 50,000-lb single-wheel load at a tire inflation pressure of 200 psi for 700 coverages.

f. A dustproof and waterproof surfacing was provided by the three membranes beneath the M8 landing mat, with no membrane repairs required, for the number of coverages listed below:

Membranes	Coverages
T1, vinyl-coated No. 8 cotton duck	360
T13, vinyl-coated nylon	500
T12, neoprene-coated nylon	700

g. Although no membrane permitted full seating of the M8 landing mat in field tests, the T12 membrane was the most satisfactory as it allowed the mat to seat approximately 80 percent.

h. The major cause of membrane failure underneath the landing mat was the cutting of the membrane by the rolled edge of the mat panel near the end joint.

i. The combination of M8 landing mat and sewn membrane panels was placed at an average rate of 287 sq ft per man-hour.

j. Membrane failures beneath the M8 landing mat were repaired satisfactorily, and no additional failures occurred in any repaired areas under subsequent traffic.

k. The tubular holes of the landing mat cut the T1 membrane but not the T12 and T13 membranes.

l. Gravel particles punctured the T1 membrane but not the nylon membranes.

m. In field tests, adhesive SBP-1146-A was the most satisfactory vinyl adhesive tested, and adhesive G-580 was adequate for bonding neoprene-coated membranes.

n. When used alone or beneath the M8 landing mat, sewn membrane panels provided a dustproof surfacing and prevented erosion of the subgrade by the direct-impingement blasts of the jet engine.

o. Tests indicated that no adhesive tested would withstand a temperature of 350 F for 5 min.

p. Joints constructed with the following adhesives failed from a 5-min exposure at the temperatures indicated:

Adhesive	Temperature, °F
Vinyl adhesive, EC-866	200
Vinyl adhesive, SBP-1146-A	250
Neoprene adhesive, G-580	300

q. The membranes and sewn joints were resistant to the jet-exhaust blast for 5 min at a temperature of 365 F.

r. The embossed surface of the T14 membrane provided the best skid resistance when dry. However, there was very little difference in the coefficients of friction of any of the membrane surfaces when wet.

Conclusions

76. Based on the results of this investigation, the following conclusions are believed warranted:

a. The T12, neoprene-coated nylon membrane is the most satisfactorily performing membrane for use as a wearing surface and beneath M8 landing mat.

b. The sewn membrane panel is more desirable than the roll of membrane for rapid construction of combat-type airfields and roads.

c. Membranes and sewn joints will withstand jet-aircraft exhaust blasts of 365 F for 5 min; however, adhesive-constructed joints will not.

d. The T1 membrane is more satisfactory for the construction of adhesive joints than are the nylon membranes, because of the selvage pucker of the nylon membranes.

e. Sharp rock particles, such as gravel or slag, located beneath the membrane surface will puncture the T1 membrane more readily than the nylon membranes.

f. The skid resistance of the nylon membrane, when wet, is not increased appreciably by embossment of the surface.

Recommendations for Future Developments

77. The specific objectives of future membrane development should be to:

a. Provide a connecting medium, other than adhesives, for the ends of sewn membrane panels, since adhesives cannot be used under all weather conditions.

b. Conduct storage tests on bundles of T1, T12, and T13 sewn membrane panels in the Panama Canal Zone to determine the durability qualities of the panels when exposed to open storage for three years.

c. Coordinate a study with coated-fabric manufacturers to improve the heat-setting process for nylon fabric and the application of elastomers to these fabrics. Improvement in these processes will reduce and/or eliminate selvage pucker of nylon fabrics.

d. Provide a standard sewn membrane panel for U. S. Army field usage.

e. Evaluate improved fabrics, elastomers, and adhesives.

Table 1

Results of Laboratory Tests on Membranes

No.	Membrane Material	Ratio of Tensile Strength to Weight	Wt lb/sq yd	Warp: At 75 F: Tensile Strength lb/in. Width	Warp: At 75 F: Elongation %	Warp: Tearing Strength lb	Warp: After 5 min at 350 F: Tensile Strength lb/in. Width	Warp: After 5 min at 350 F: Elongation %	Water Resistance	Warp: After 150 hr Weatherometer: Tensile Strength lb/in. Width	Warp: After 150 hr Weatherometer: Elongation %	Temperature, High, Effect on Cloth Blocking	Temperature, Low, Effect on Coated Cloth	Fire Resistance: After Flame* sec	Fire Resistance: Char Length in.	Jet Fuel Resistance JP-4, 24 hr
T1	No. 8 cotton duck, vinyl-coated	89	2.20	196	30.0	20	182	33.3	No leakage	180	27.6	Satisfactory	Satisfactory	1.7	1.50	Satisfactory
T12	8-oz nylon fabric, neoprene-coated	179	2.62	469	35.0	66	468	37.2	No leakage	457	30.9	Satisfactory	Satisfactory	0	0.75	Satisfactory
T13	8-oz nylon fabric, vinyl-coated	293	1.50	440	43.0	58	412	45.0	No leakage	440	43.0	Satisfactory	Satisfactory	1.3	0.25	Satisfactory
T14	8-oz nylon fabric, neoprene-coated, embossed surface	159	3.00	476	34.1	74	486	36.6	No leakage	481	35.9	Satisfactory	Satisfactory	0	1.00	Satisfactory
Test method used			5041**	5102**		5134**	5102**		5516**	5804**		5872**	5874**	5902** for neoprene-coated nylon and No. 8 cotton duck; 5910** for vinyl-coated nylon		†

* After flame time is the time the specimen continues to flame after the burner flame is removed from the specimen.
** Federal Specification CCC-T-191b.
† Test method developed at the WES.

Table 2

Results of Laboratory Tests on Adhesives

Adhesive	Type (Liquid)	Color	Base	Wt per Gallon lb	Solids %	Solvent (Cleanup)	Solvent (Dilution)	Storage months	Adhesive Shear Strength,* lb/2 sq in.			
									75 F	1 hr at 170 F	5 min at 350 F	After 24-hr Immersion in Water
G-580	Neoprene	Light tar	Synthetic rubber resin	7.0	25.0	Toluol	MEK**	12+	295	285	308	292
SBP-579-3A	Vinyl	Light amber	Synthetic rubber resin	7.9	24.5	MEK	MEK	12+	224	215	218	220
SBP-1146-A	Vinyl	Clear amber	Synthetic rubber resin	6.2	20.8	MEK	MEK	12+	205	196	192	210
EC-866	Vinyl	Transparent	Synthetic rubber resin	7.6	25.0	MEK	MIK**	12+	214	203	212	218
Test method used										5102†		5964†

* Adhesive was allowed to cure for 24 hr at 75 F, then exposed to temperatures for times indicated, and tested according to Federal Specification CCC-T-191b, Method 5102. (Cut strip 2 in. wide with 1-in. lap joint.)

** MEK, Methyl Ethyl Ketone; MIK, Methyl Isobutyl Ketone.

† Federal Specification CCC-T-191b

Table 3

Summary of CBR, Density, and Water-Content Determinations, Test Lane 1

Section	Depth in.	0 Coverages			40 Coverages			174 Coverages			350 Coverages		
		Water Content % Dry Wt	Dry Density lb/cu ft	CBR	Water Content % Dry Wt	Dry Density lb/cu ft	CBR	Water Content % Dry Wt	Dry Density lb/cu ft	CBR	Water Content % Dry Wt	Dry Density lb/cu ft	CBR
1	2	12.8	107.7	42	11.3	108.5	56	10.6	108.9	60	11.0	108.8	53
2	2	11.7	106.9	50	10.3	106.1	52	11.4	107.2	55	10.0	107.4	51
3	2	12.7	105.9	41	10.6	106.8	54	10.1	106.1	56	10.2	106.0	52
4	2	13.9	105.6	41	10.4	106.2	51	11.1	107.9	61	10.9	105.8	52
5	2	13.6	108.7	40	10.6	103.8	45	11.2	106.5	59	9.8	105.8	53
6	2	14.0	108.4	42	11.4	105.1	49	11.4	109.1	59	11.0	109.0	58

Table 4

Summary of CBR, Density, and Water-Content Determinations

Test Lane 2

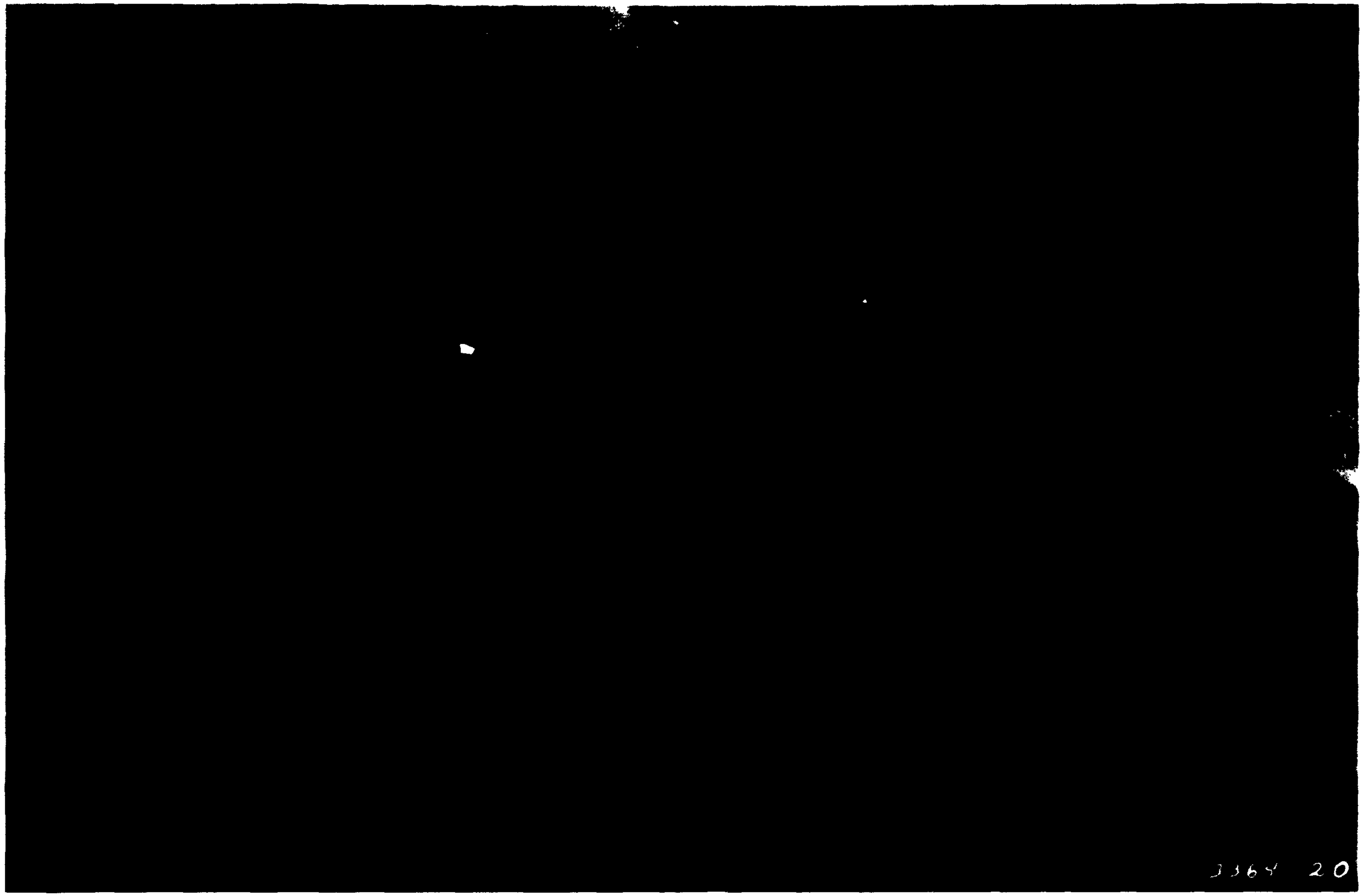
Section	Depth in.	0 Coverages			350 Coverages			700 Coverages		
		Water Content % Dry Wt	Dry Density lb/cu ft	CBR	Water Content % Dry Wt	Dry Density lb/cu ft	CBR	Water Content % Dry Wt	Dry Density lb/cu ft	CBR
A	Surface	10.9		38	10.9		54	12.4		71
	2	11.2	105.8	35	11.4	110.8	59	10.5	107.8	58
	8	11.1	106.8	41				11.0	107.3	46
	14	11.9	108.8	38				11.8	105.6	27
	20	13.8	109.2	21				14.2	108.6	30
	26							17.2	111.7	19
B	Surface	11.8		36	11.5		65	9.9		78
	2	11.6	108.0	38	12.1	110.6	73	11.2	109.0	62
	8	12.8	107.3	39				12.8	111.2	60
	14	12.6	106.8	34				12.5	107.7	41
	20	13.0	110.0	36				14.2	112.7	42
	26	14.8	113.0	32				15.1	114.0	39
C	Surface	12.7		34	10.9		66	11.0		57
	2	12.3	107.7	33	11.7	107.8	53	11.0	109.7	55
	8	13.2	107.7	37				12.8	110.2	59
	14	13.6	108.0	37				12.7	107.6	40
	20	12.8	109.0	37				14.5	109.1	36
	26	15.0	110.9	33				14.9	112.1	48
D	Surface	11.2		39	10.5		58	10.7		54
	2	10.7	105.7	35	10.7	109.1	59	11.0	109.0	56
	8	12.1	106.5	35				11.8	108.3	52
	14	12.8	107.4	37				13.0	107.1	33
	20	13.2	108.7	38				14.5	108.4	34
	26	14.4	108.7	34				14.6	112.3	47
E	Surface	11.9		37	10.5		52	10.1		53
	2	11.7	106.4	36	10.9	109.1	58	10.8	108.6	58
	8	11.4	106.2	32				11.6	106.8	56
	14	13.0	108.6	43				12.9	105.7	39
	20	13.8	109.0	35				14.5	108.9	36
	26	14.1	109.8	34				14.1	108.7	31
F	Surface	10.3		36	10.7		57	9.6		55
	2	10.1	105.0	36	11.1	110.2	59	10.1	110.2	60
	8	12.8	106.8	35				11.1	108.5	59
	14	12.5	105.5	33				12.4	106.3	36
	20	13.5	106.6	35				13.9	107.0	30
	26	14.6	108.3	30				13.9	107.5	30
G	Surface	13.3		39	10.5		56	10.4		53
	2	11.7	107.0	35	11.2	110.1	52	11.2	109.4	58
	8	12.9	107.6	42				13.0	109.7	61
	14	12.7	105.5	39				11.8	105.8	35
	20	13.1	106.4	32				13.7	106.9	30
	26	13.7	107.8	31				14.2	109.3	38

Table 5

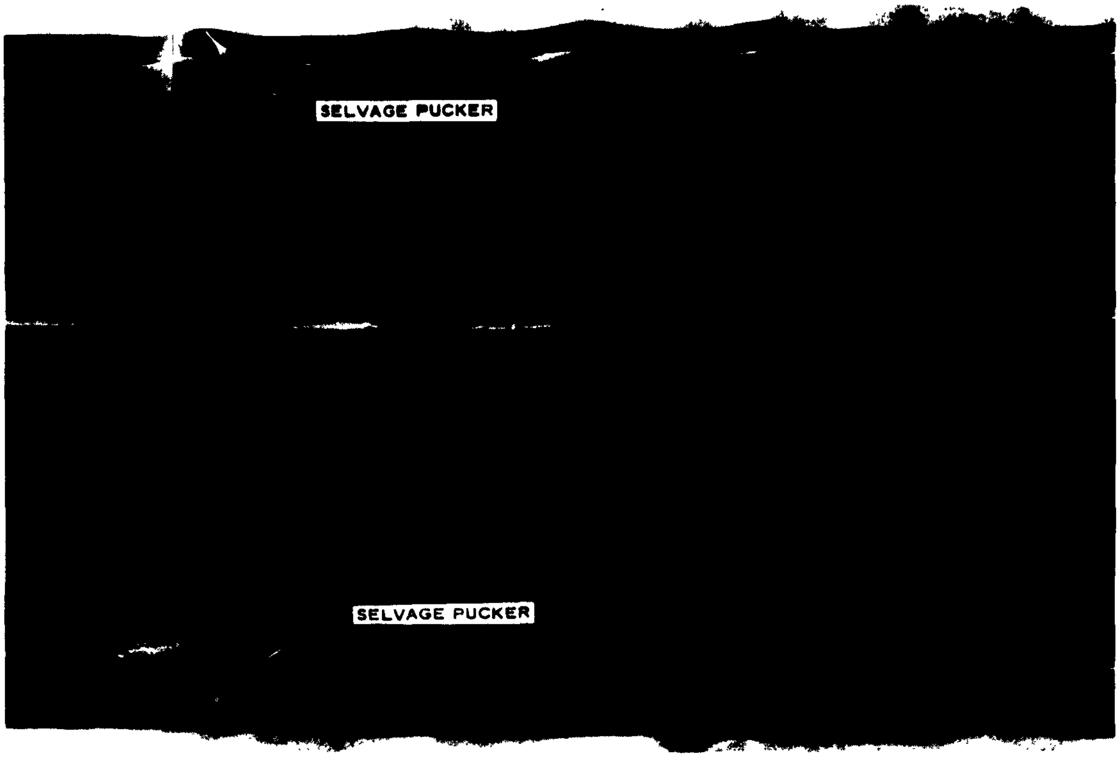
Summary of Data for Skid-Resistance and Tire-Wear Tests*

Test Section No.	Type of Membrane	Condition of Surface	Length of Pull ft	Average Force** lb	Coefficient of Friction	Degree of Tire Wear	Remarks
D	T14, embossed neoprene-coated nylon	Dry	13.5	11,200	0.56	Negligible	No membrane or joint damage
		Wet	15.6	3,600	0.18	Negligible	
E	T12, smooth neoprene-coated nylon	Dry	15.6	9,600	0.48	Negligible	No membrane or joint damage
		Wet	18.2	3,200	0.16	Negligible	
F	T13, smooth vinyl-coated nylon	Dry	12.6	8,800	0.44	Negligible	Vinyl coating was peeled from nylon fabric. No joint damage
		Wet	9.5	3,200	0.16	Negligible	
G	T1, smooth vinyl-coated cotton duck	Dry	20.0	10,400	0.52	Negligible	No membrane or joint damage
		Wet	13.6	3,600	0.18	Negligible	

* Test conducted with 10,000-lb single-wheel load and 200-psi tire pressure.
** Force required to keep load cart moving.

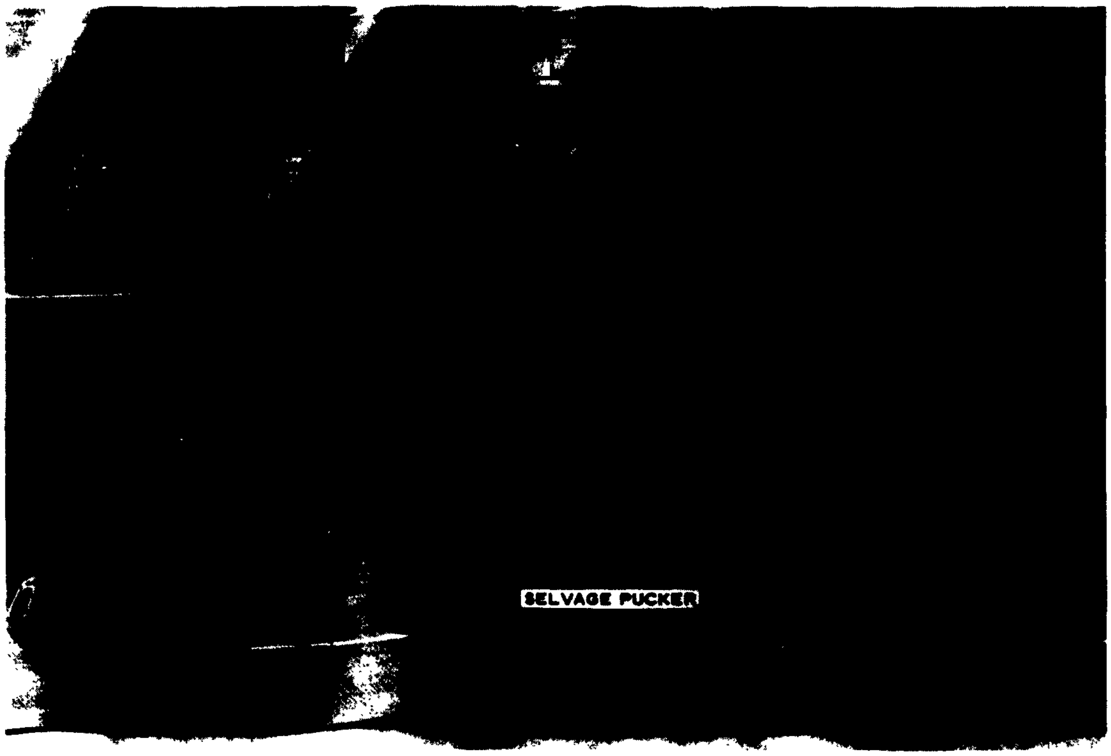


Photograph 1. Completed adhesive joints of T1 cotton duck membrane, section 1, lane 1



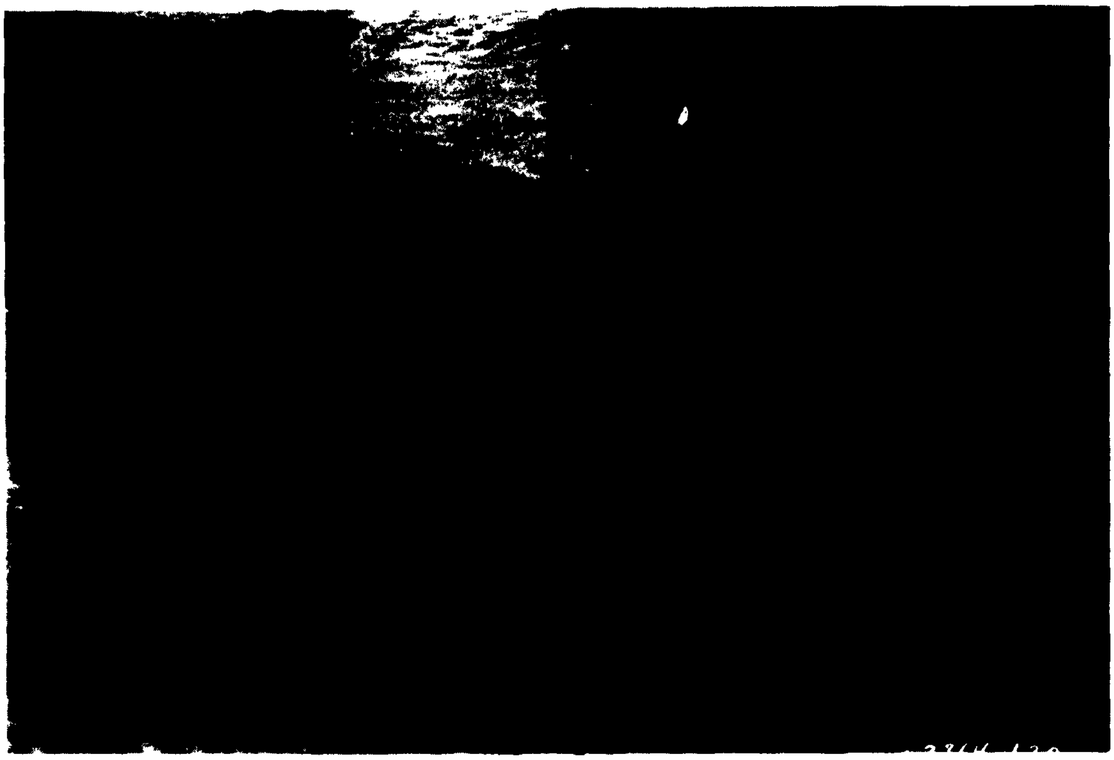
Photograph 2. Selvage pucker of T13 nylon membrane, section 3, lane 1

Photograph 3. Puckered adhesive joint of T13 nylon membrane, section 3, lane 1

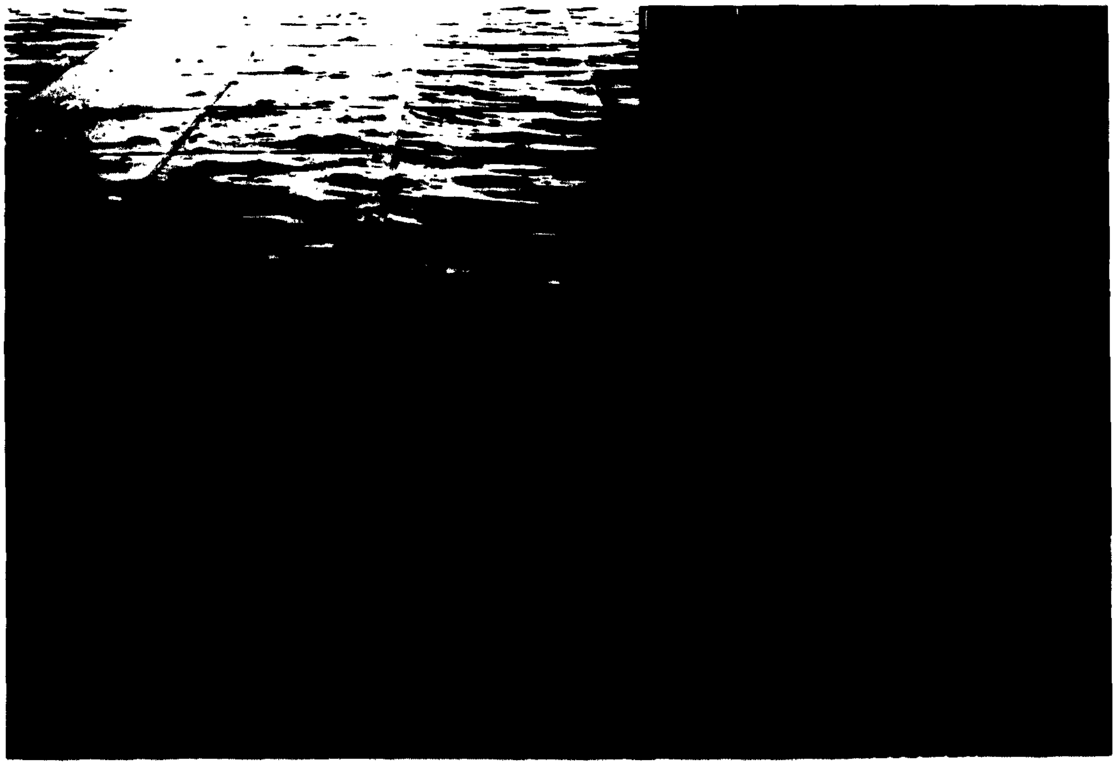


Photograph 4. Selvage pucker of T12 nylon membrane used on section 5, lane 1

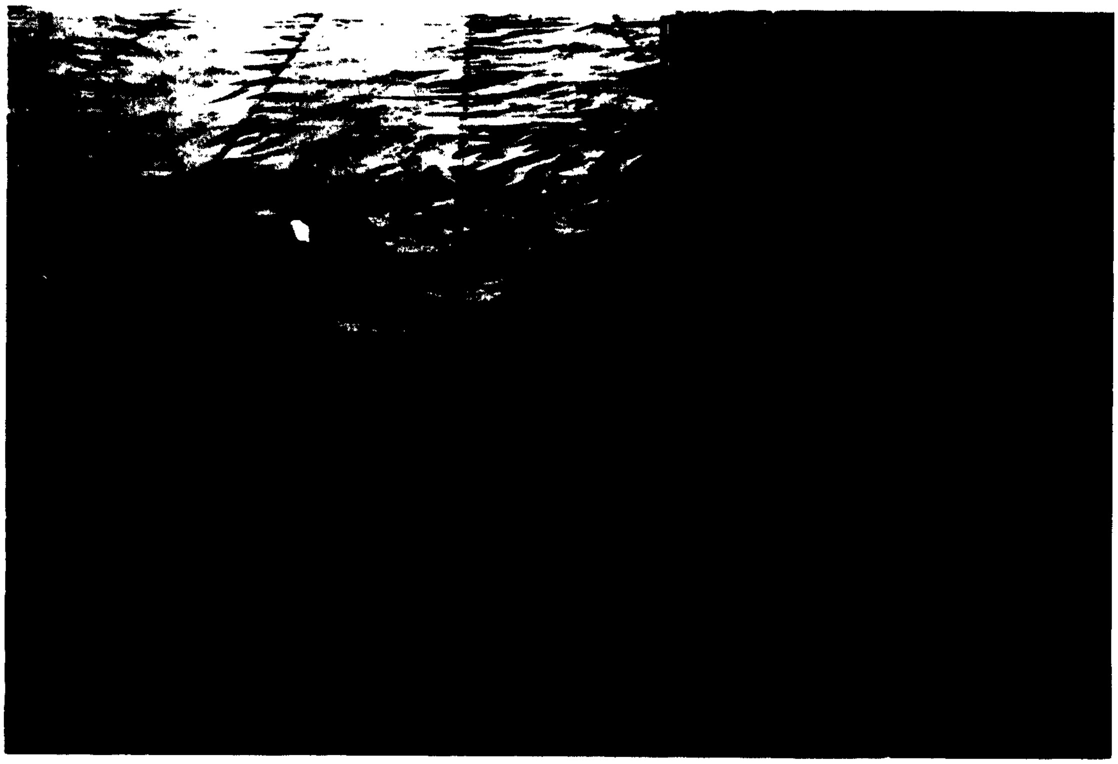
Photograph 5. Completed T12 nylon membrane surfacing, section 5, lane 1



Photograph 6. Sewn panel of T1 cotton duck on section A, lane 2, prior to placement of mat

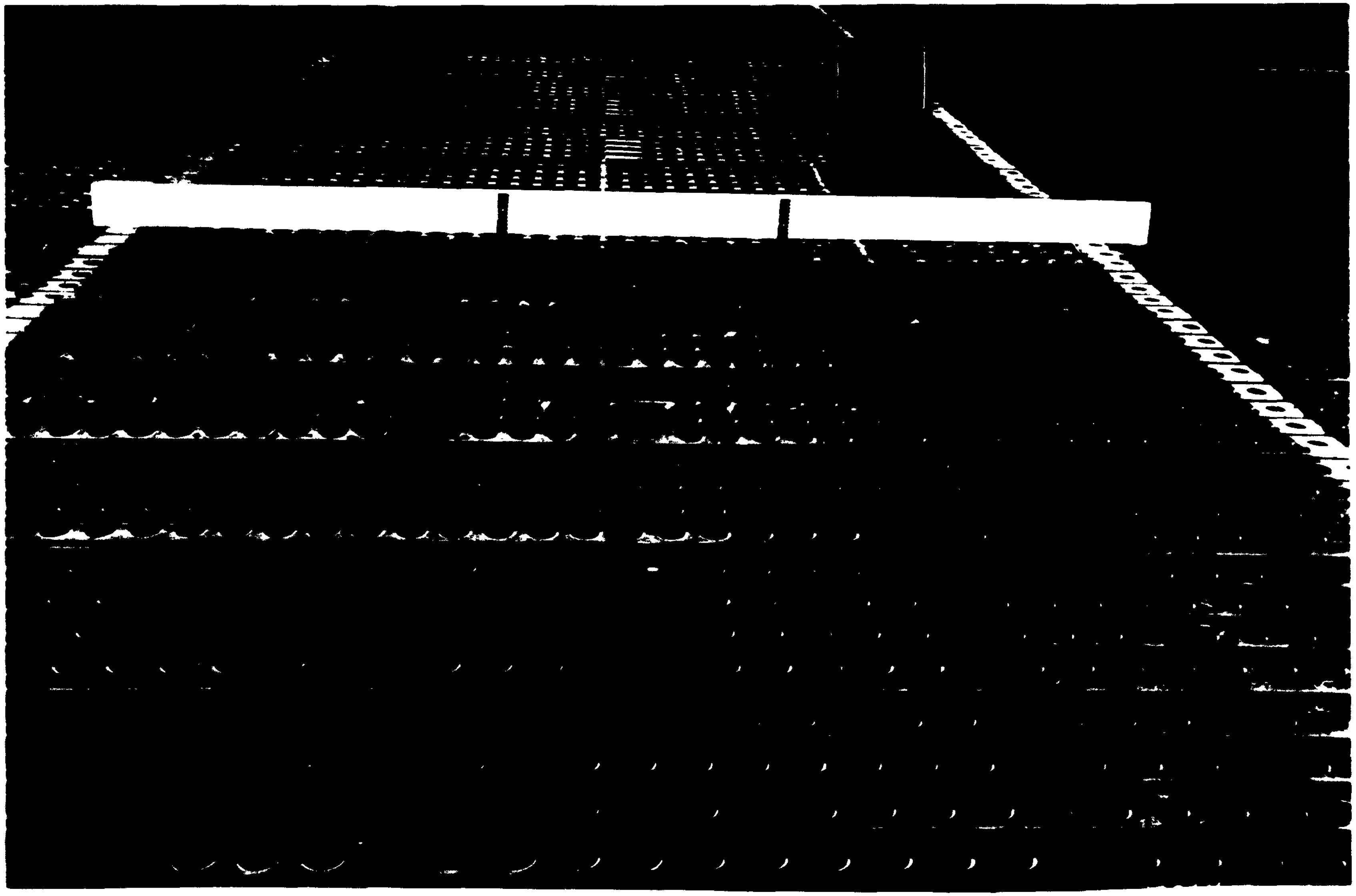


Photograph 7. Sewn panel of T13 nylon on section B, lane 2, prior to placement of mat



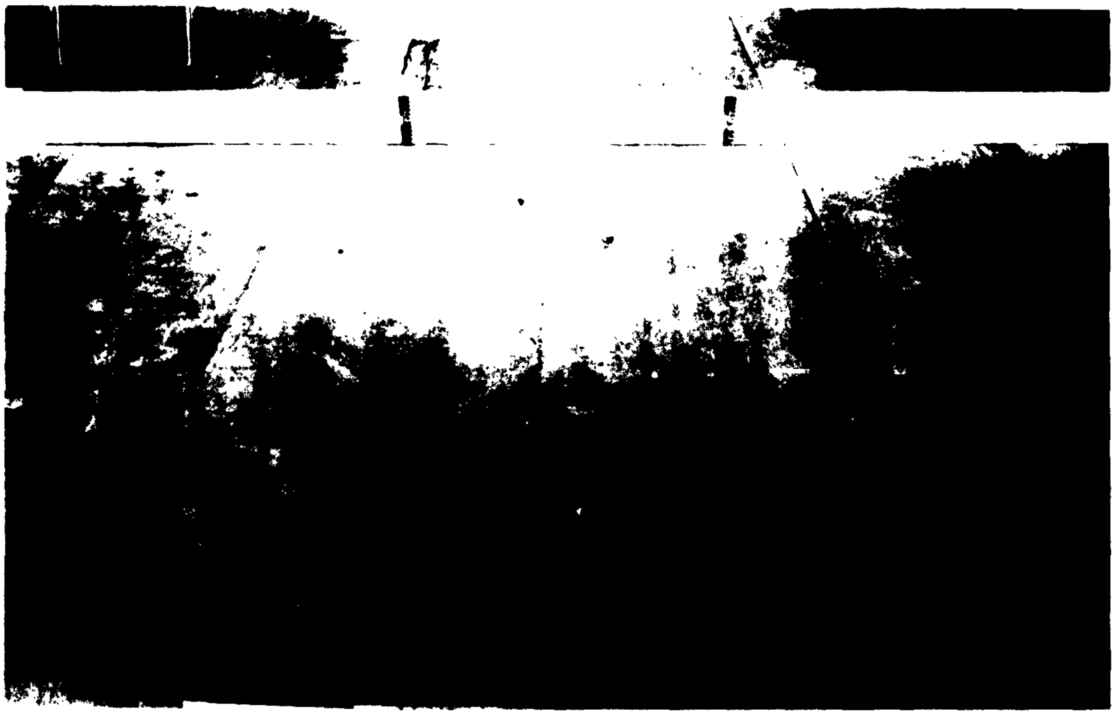
Photograph 8. Sewn panel of T12 nylon on section C, lane 2, prior to placement of mat

Photograph 9. Sewn panel of T14 nylon on section D, lane 2, prior to start of traffic

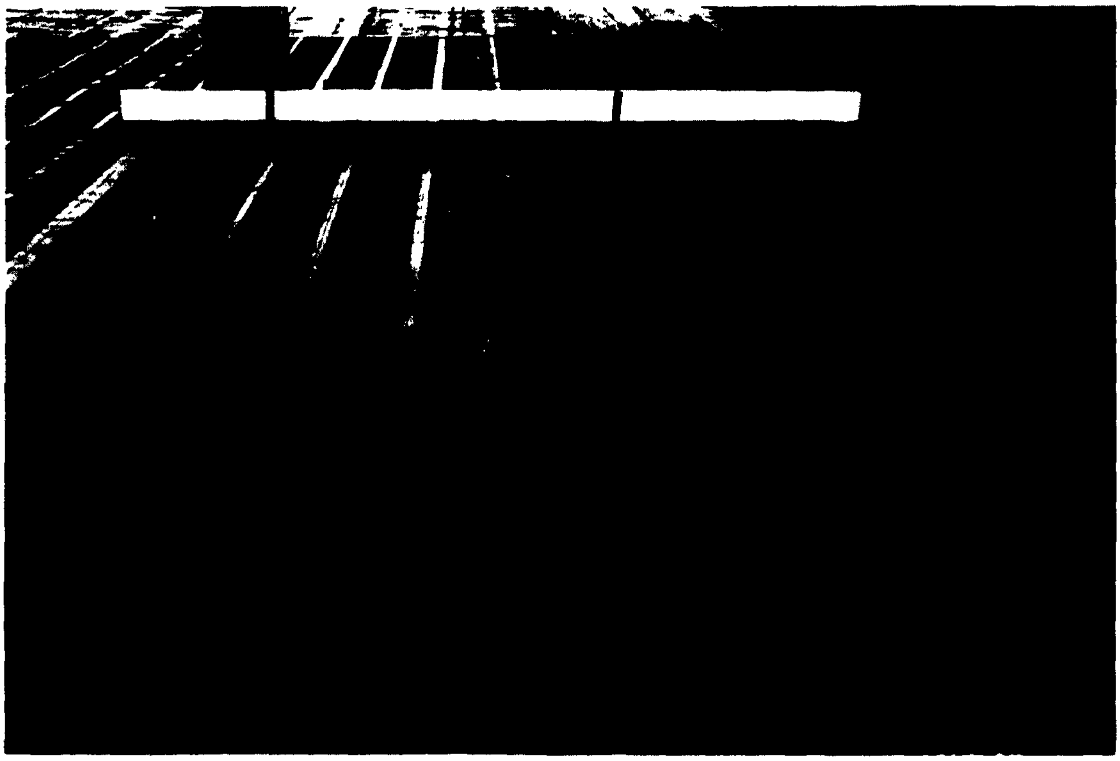


Photograph 10. Landing mat-membrane surfaced section C, lane 2, prior to start of traffic

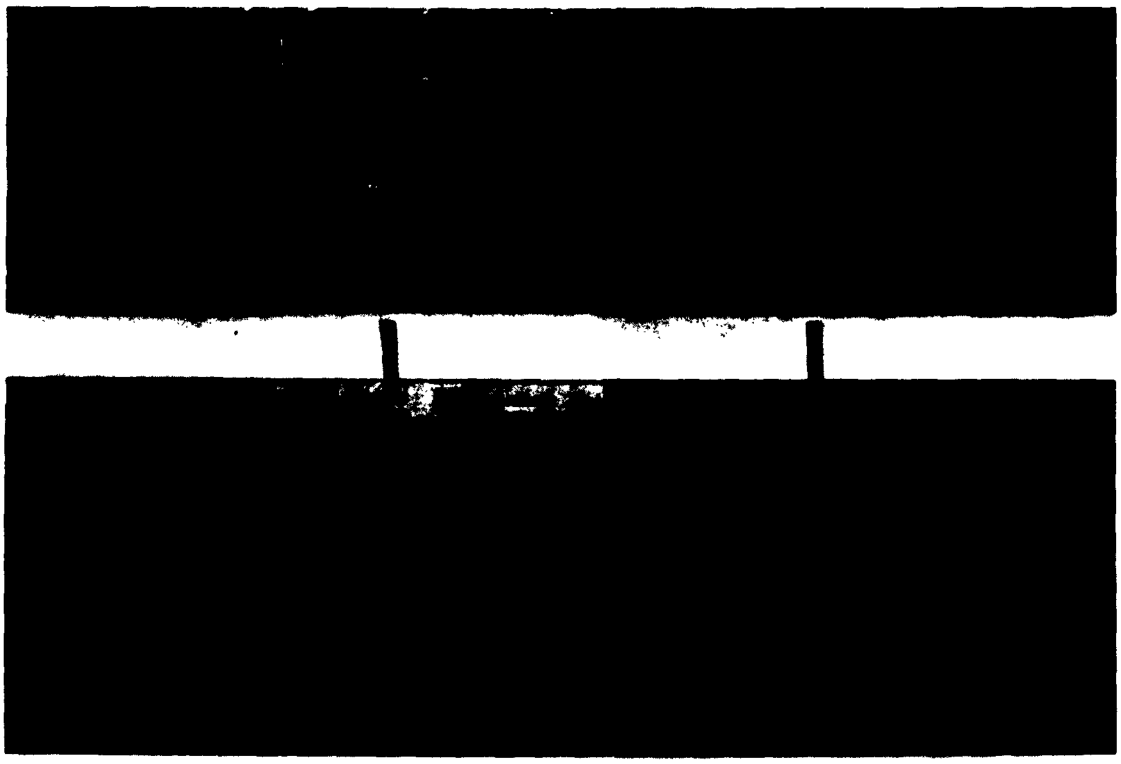
Photograph 11. Section 1, lane 1, prior to start of traffic tests



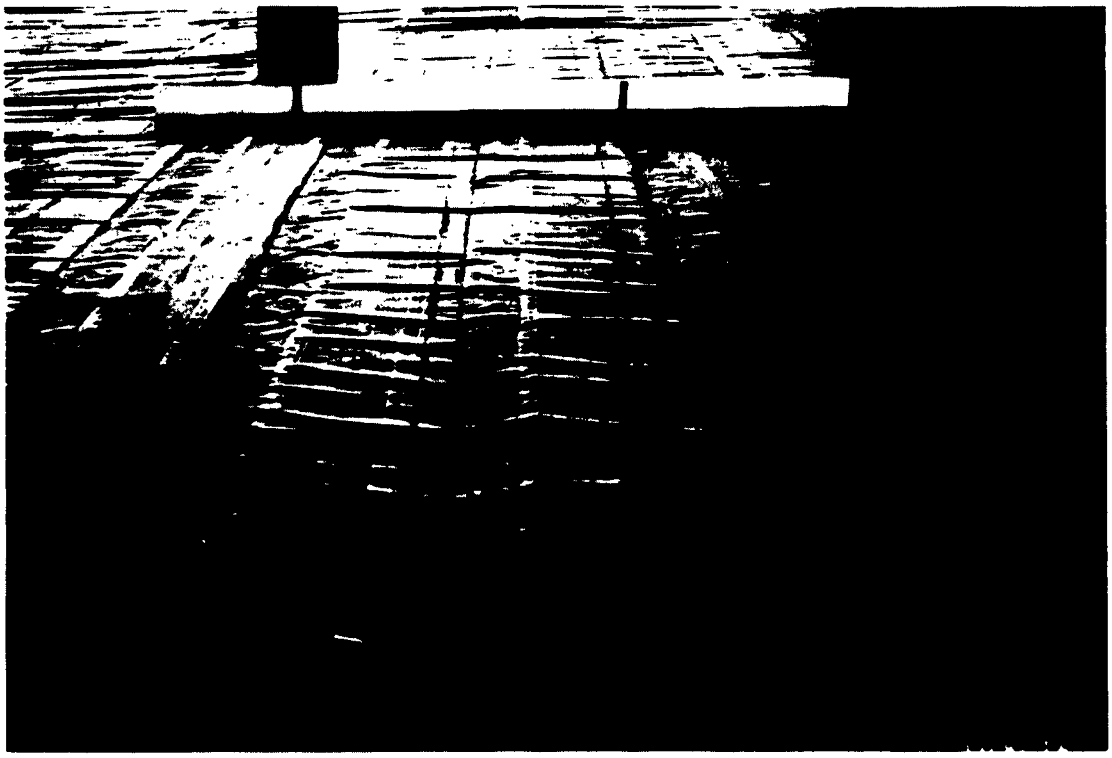
Photograph 12. Section 1, lane 1, after 350 coverages



Photograph 13. Section 2, lane 1, prior to start of traffic tests

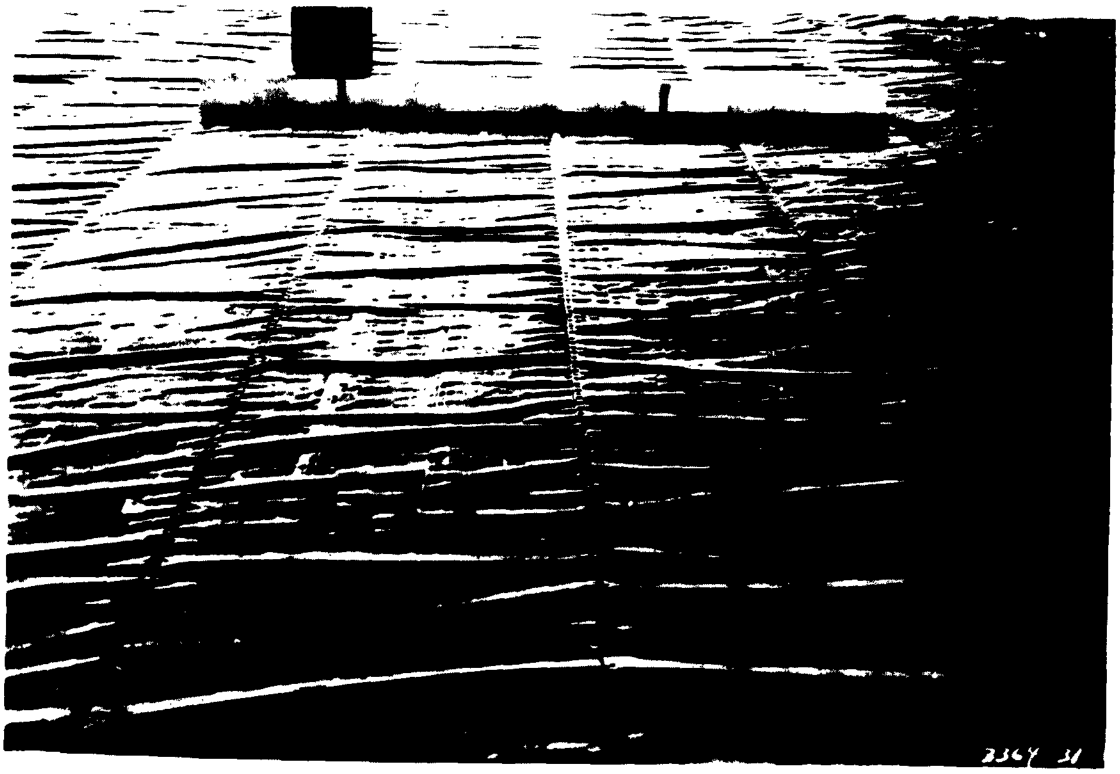


Photograph 14. Section 2, lane 1, after 350 coverages

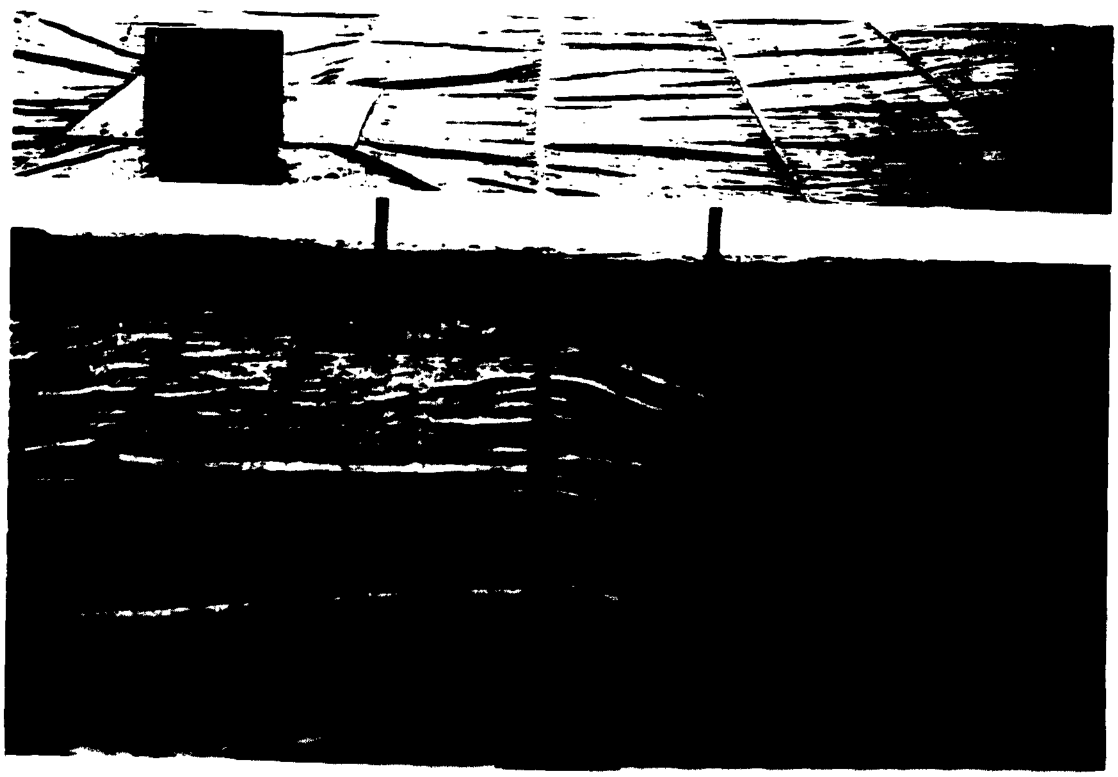


Photograph 15. Section 3, lane 1, prior to start of traffic tests

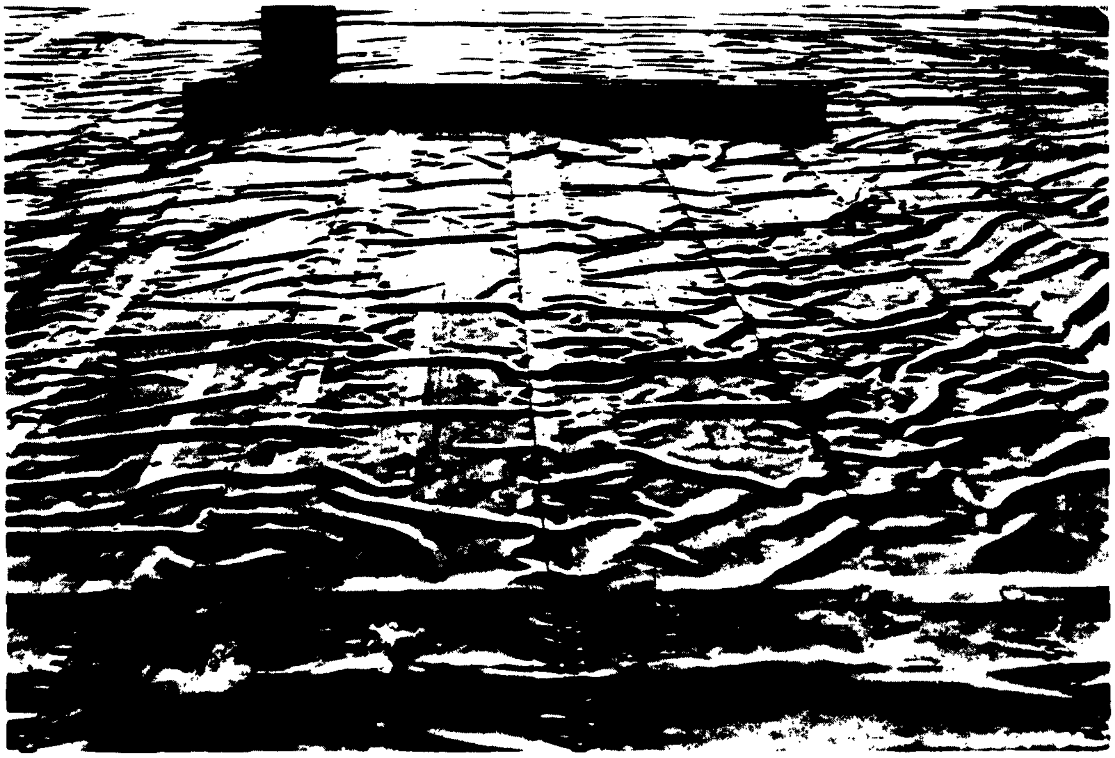
Photograph 16. Section 3, lane 1, after 350 coverages



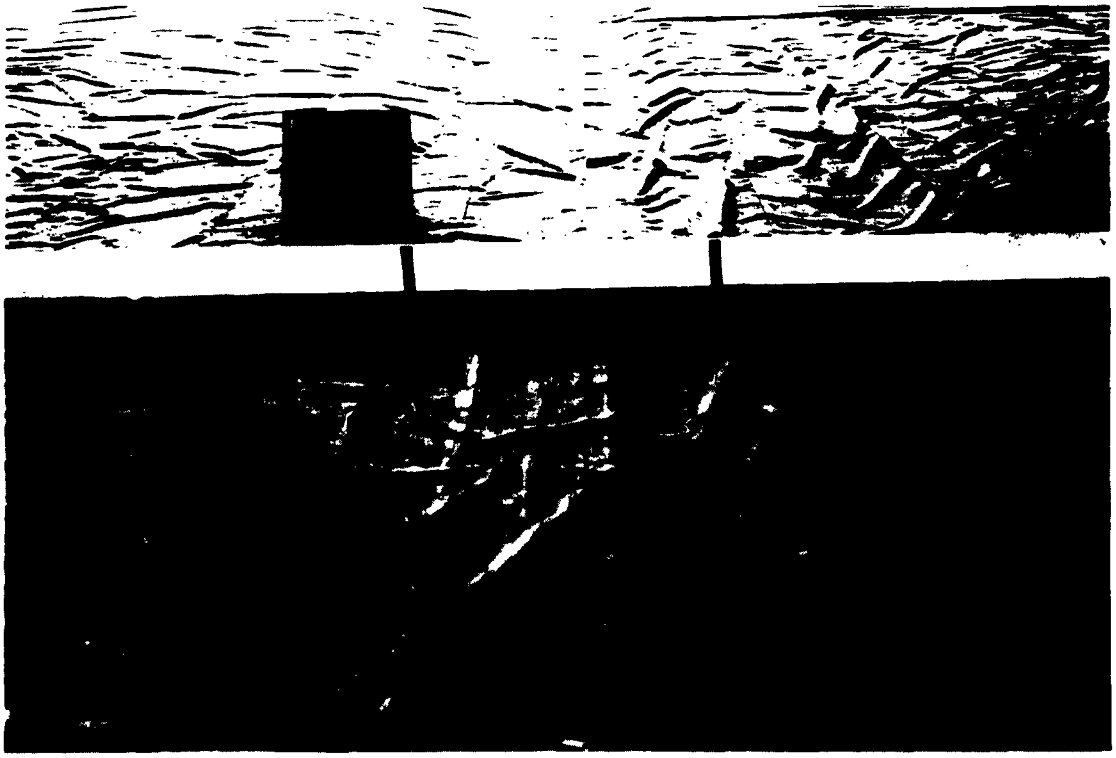
Photograph 17. Section 4, lane 1, prior to start of traffic tests



Photograph 18. Section 4, lane 1, after 350 coverages



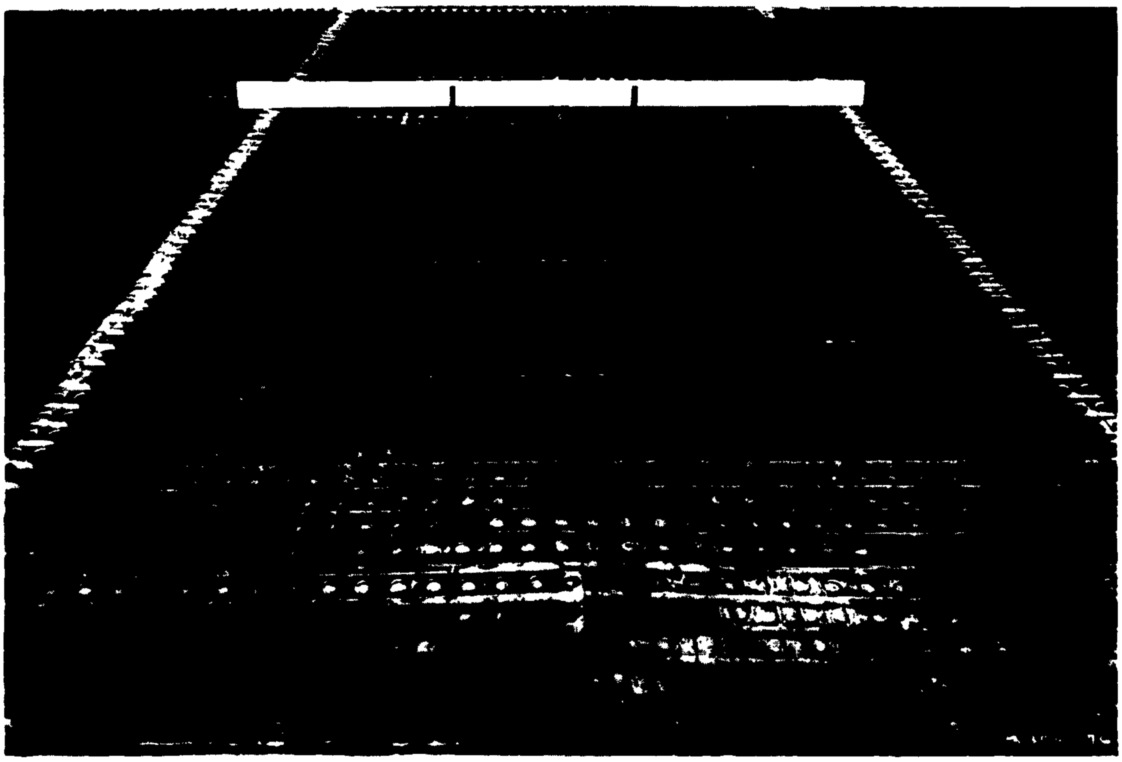
Photograph 19. Section 5, lane 1, prior to start of traffic tests



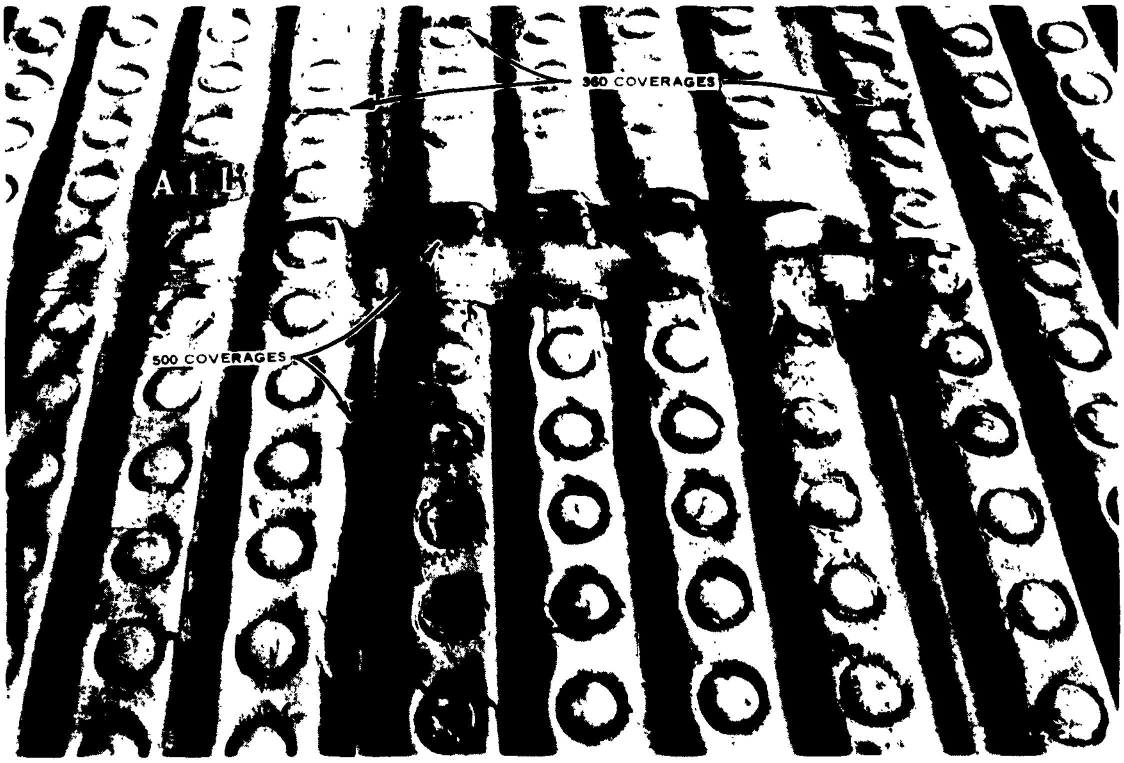
Photograph 20. Section 5, lane 1, after 350 coverages

Photograph 21. Section 6, lane 1, prior to start of traffic tests

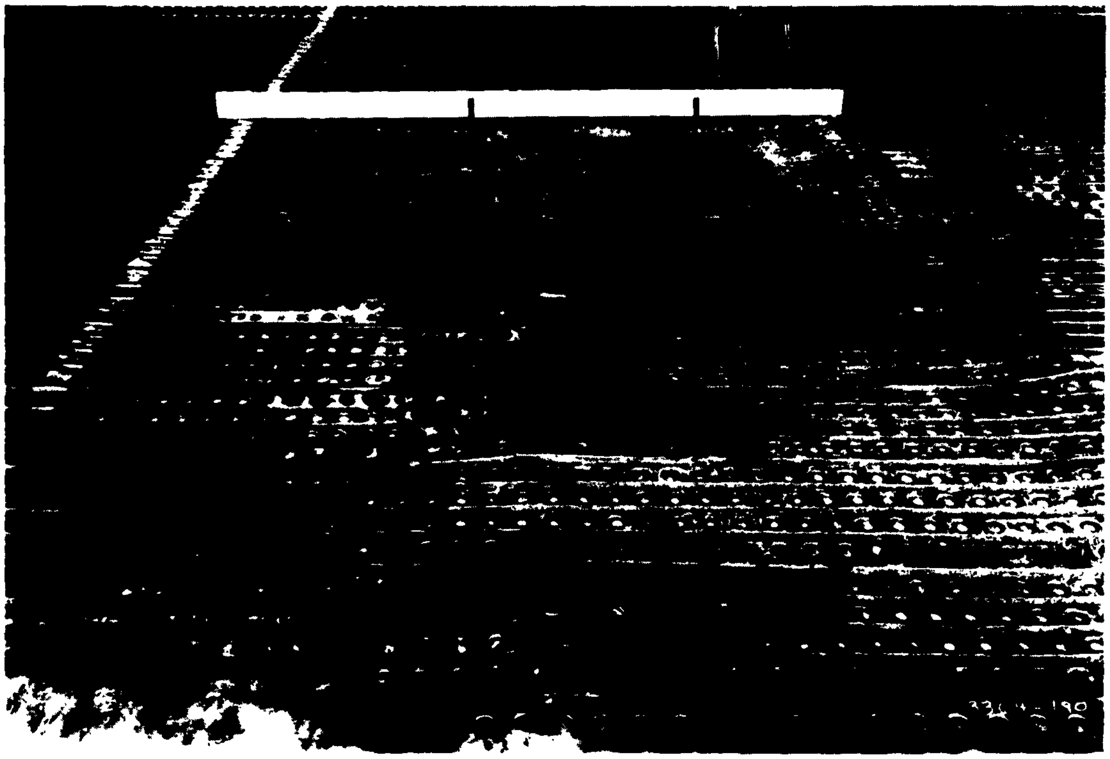
Photograph 22. Section 6, lane 1, after 350 coverages



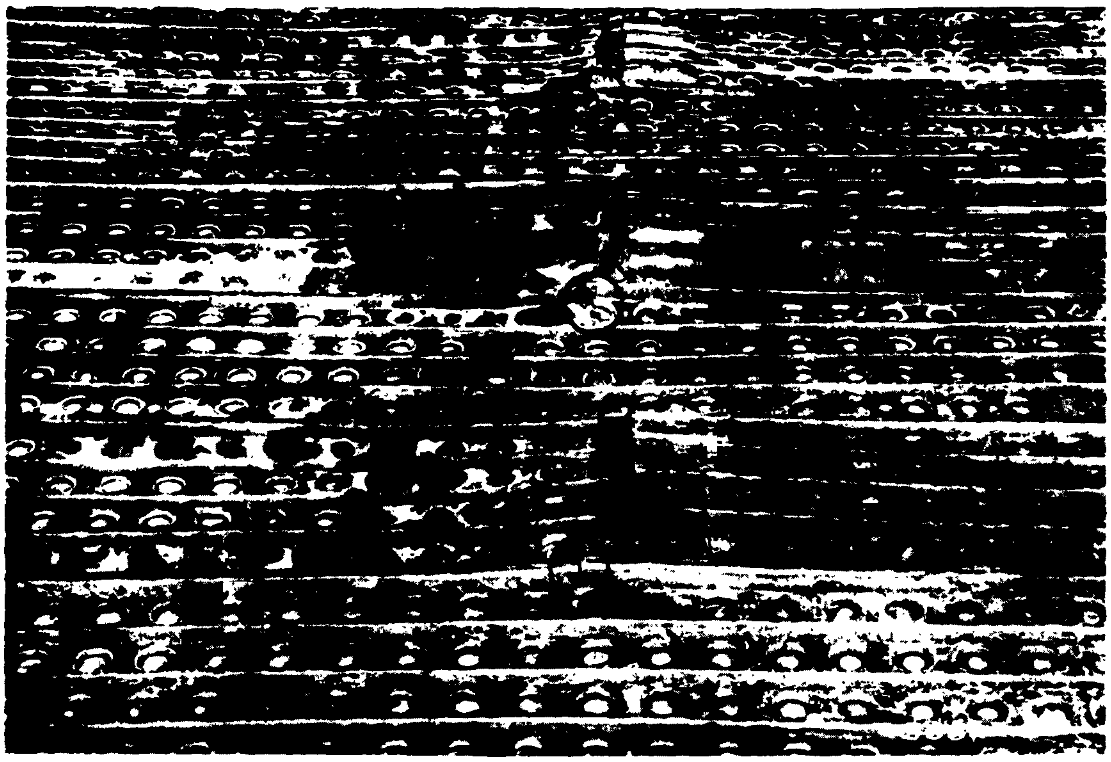
Photograph 23. Section A, lane 2, after 350 coverages



Photograph 24. Section A, lane 2. Note failures of T1 cotton duck membrane caused by tubular holes (360 coverages) and end of mat panel (500 coverages)

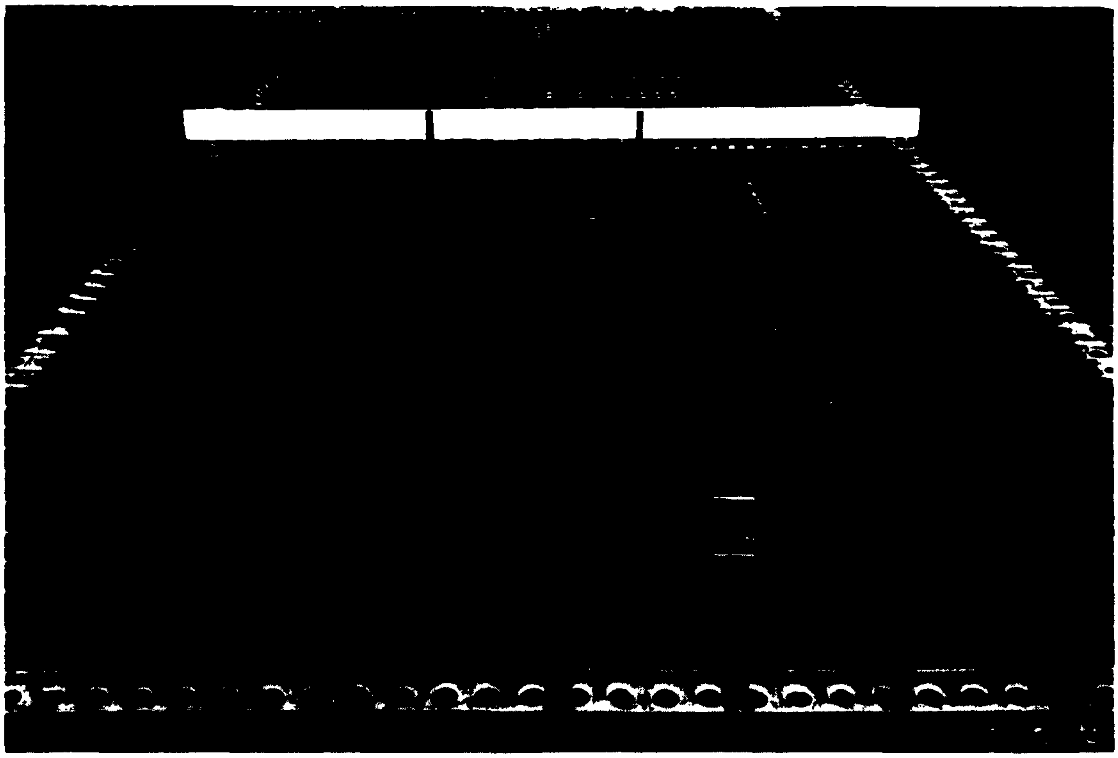


Photograph 25. Section A, lane 2, after 700 coverages

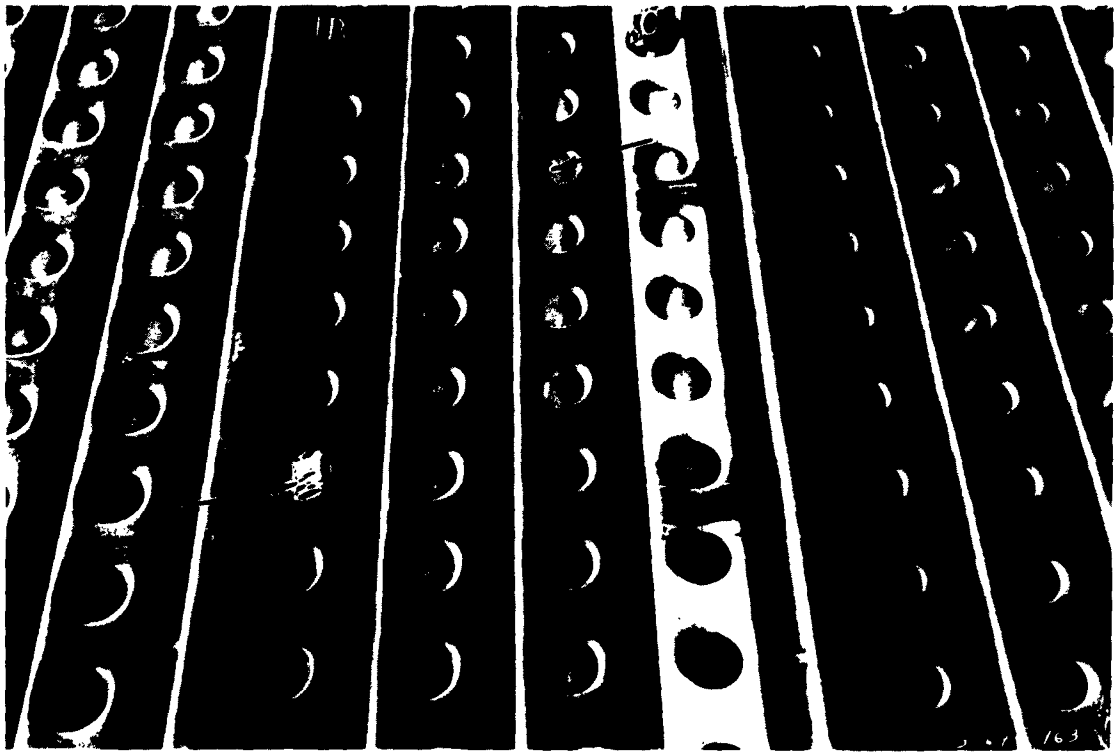


Photograph 26. Typical breaks in landing mat on section A, lane 2, after 700 coverages

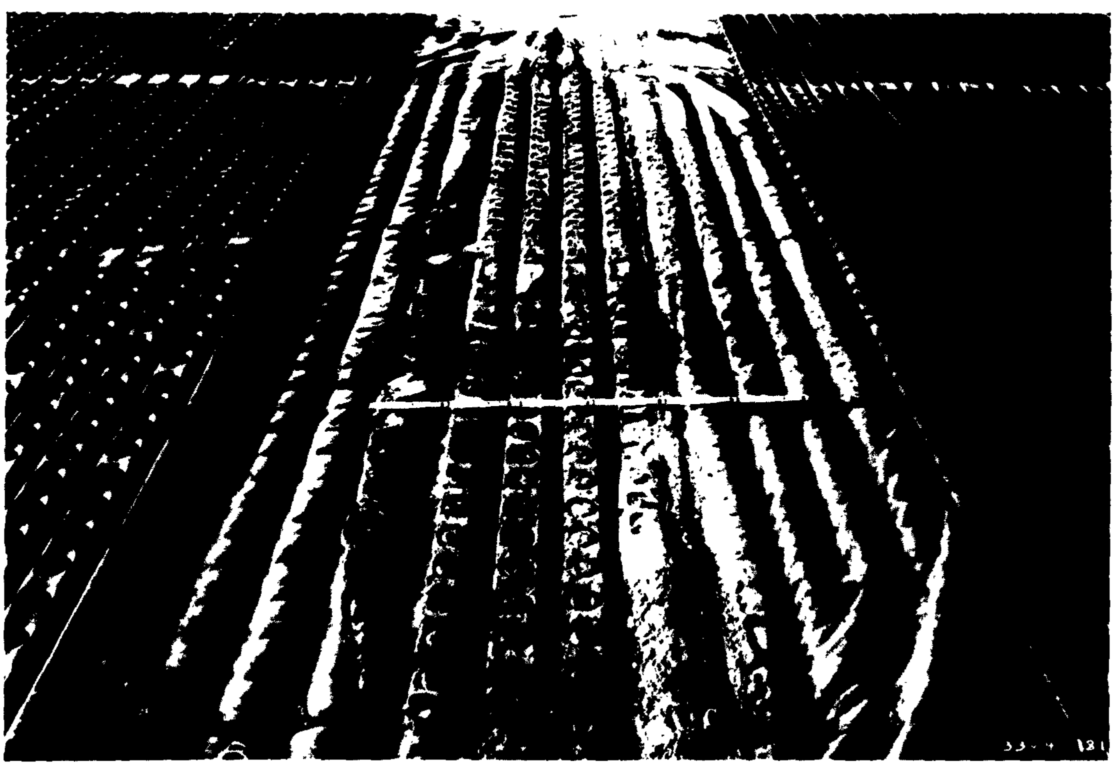
Photograph 27. Failure of T1 membrane caused by rolled edge of mat after 700 coverages on section A, lane 2



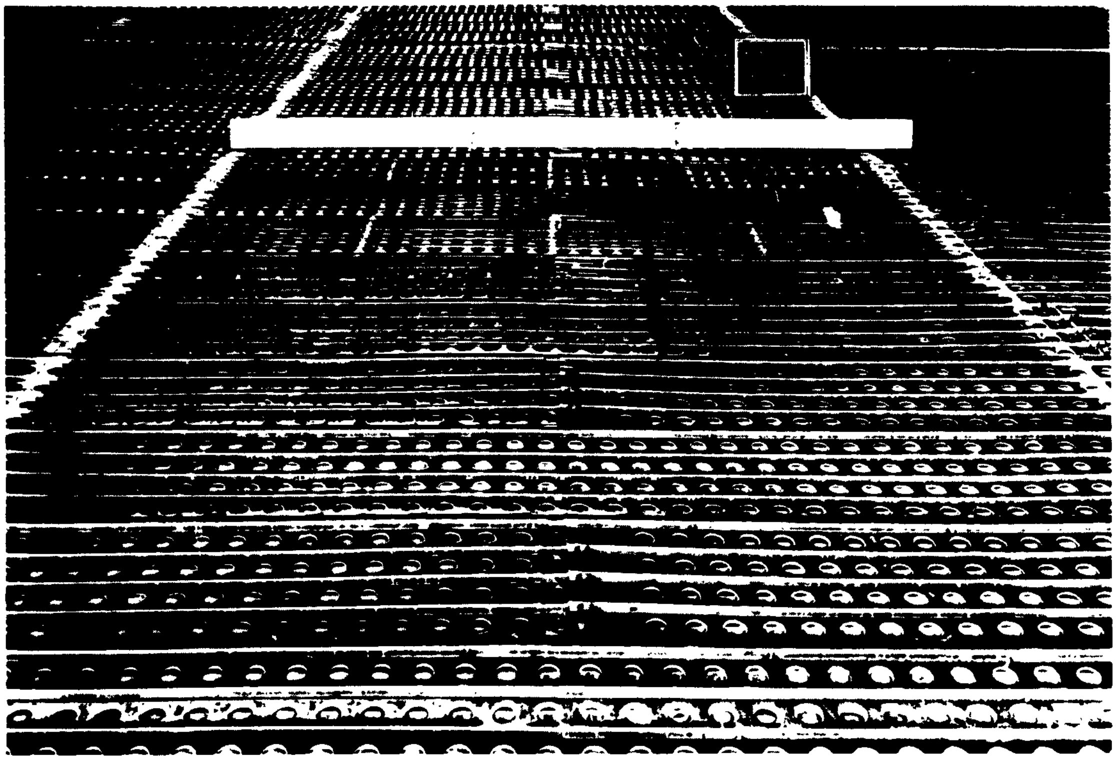
Photograph 28. Section B, lane 2, after 350 coverages



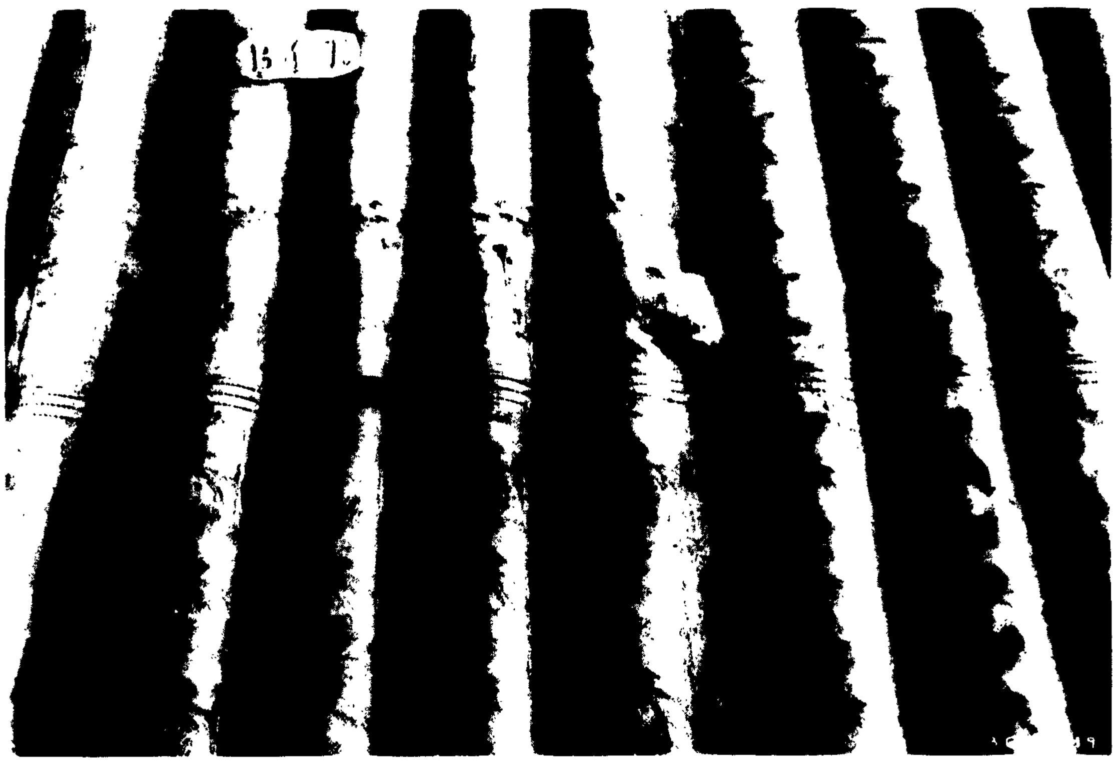
Photograph 29. Failure of sewn transition joint between sections B and C, lane 2, after 350 coverages



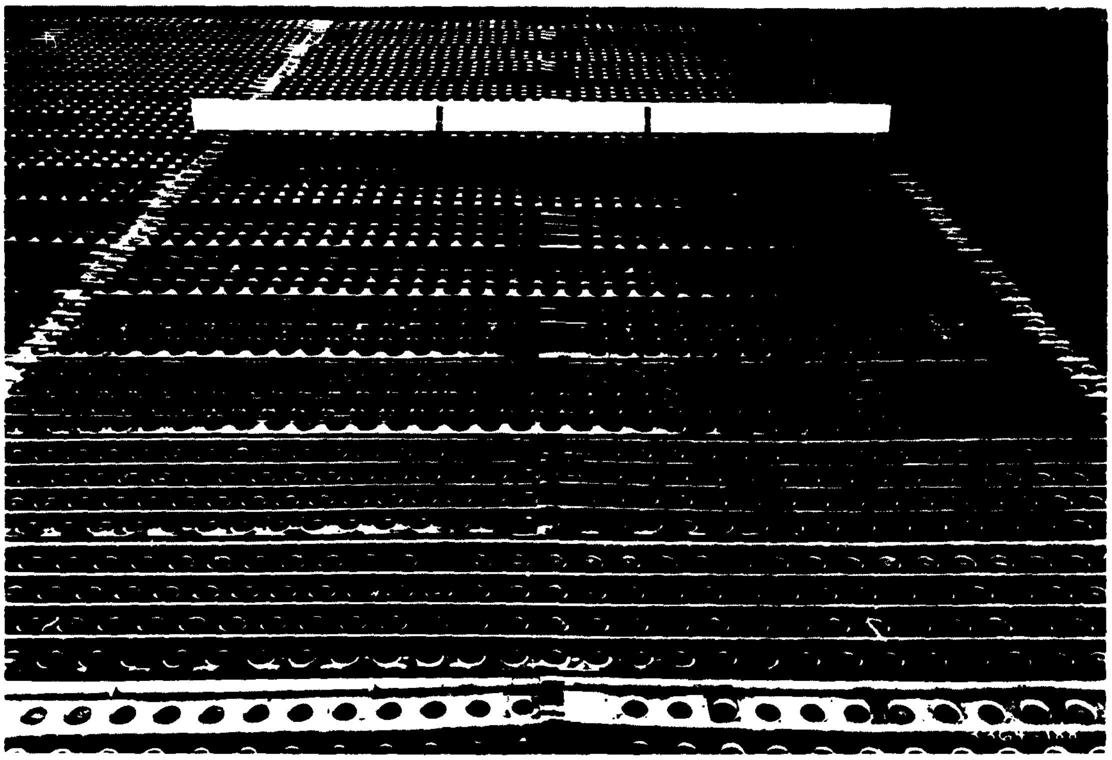
Photograph 30. Separation of membrane surfacing on lane 2 caused by failure of transition joint between sections B and C



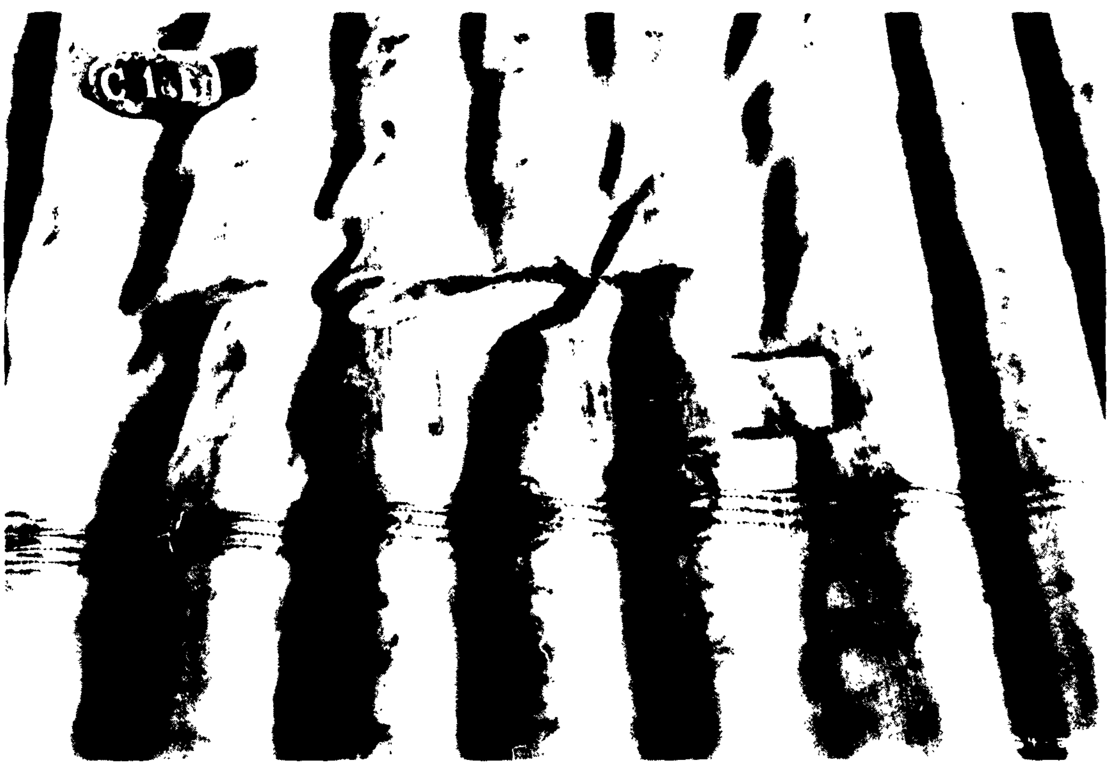
Photograph 31. Section B, lane 2, after 700 coverages



Photograph 32. Damage to T13 membrane by landing mat after 700 coverages, section B, lane 2

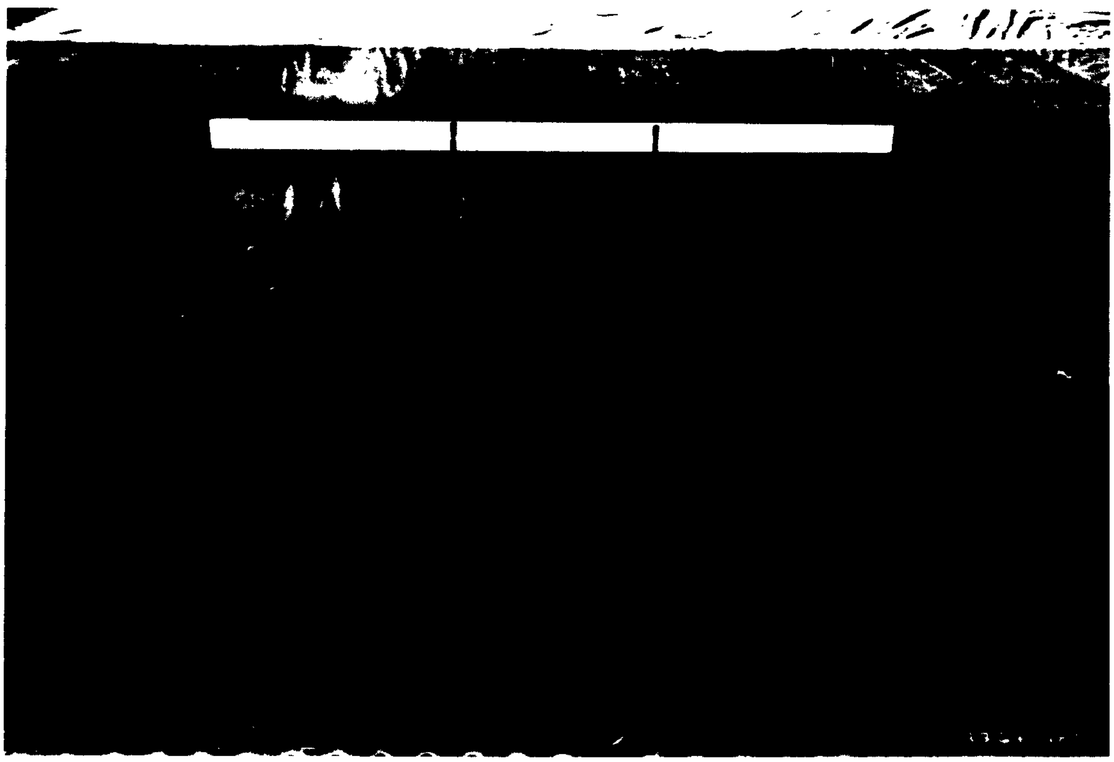


Photograph 33. Section C, lane 2, after 700 coverages



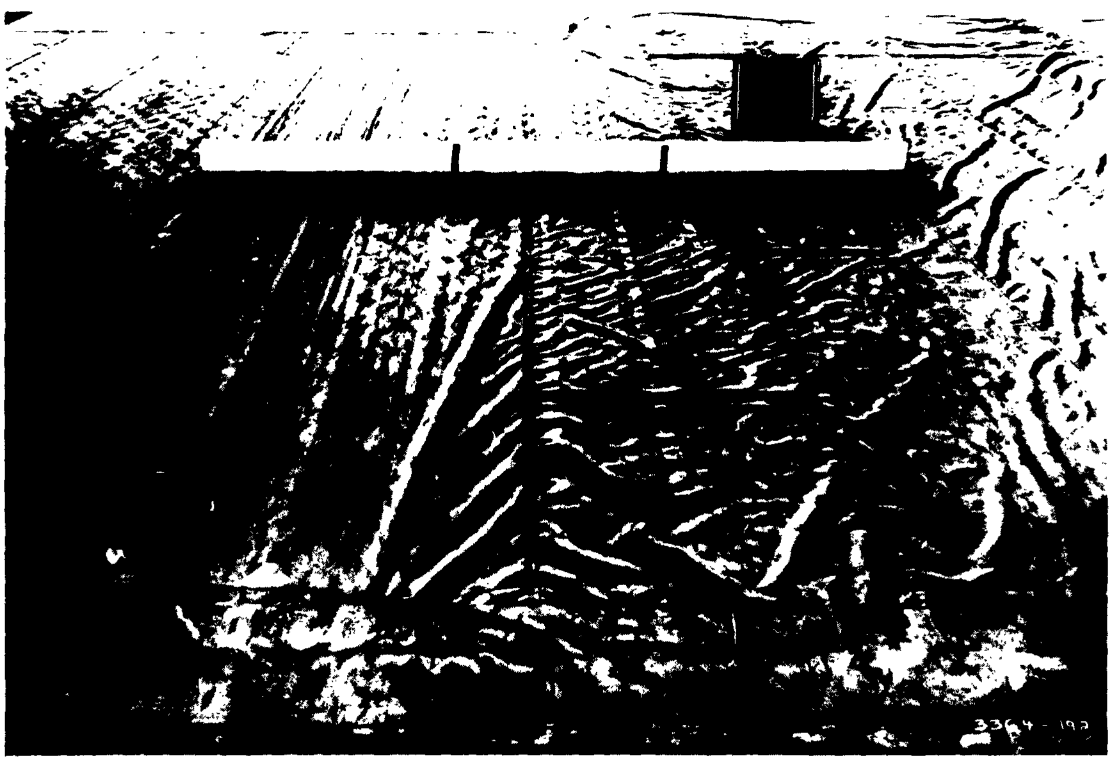
Photograph 34. Damage to T12 membrane from landing mat after 700 coverages, section C, lane 2

Photograph 35. Section D, lane 2, prior to start of traffic tests



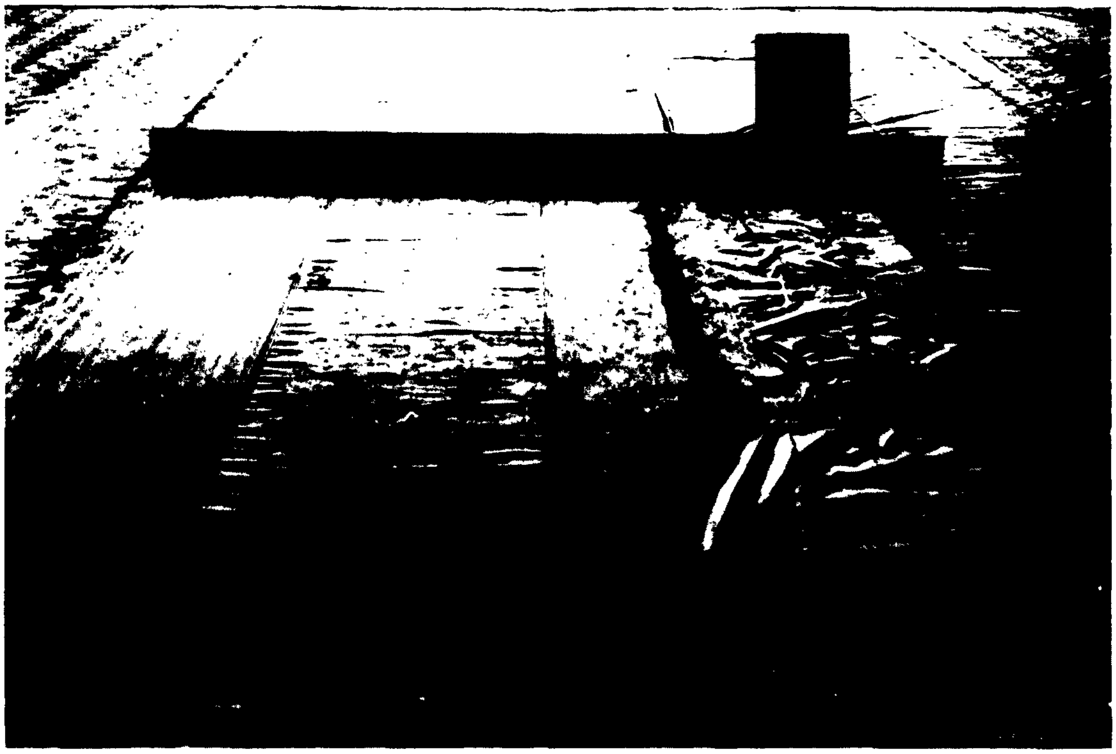
Photograph 36. Section D, lane 2, after 700 coverages

Photograph 37. Section E, lane 2, prior to start of traffic tests



Photograph 38. Section E, lane 2, after 700 coverages

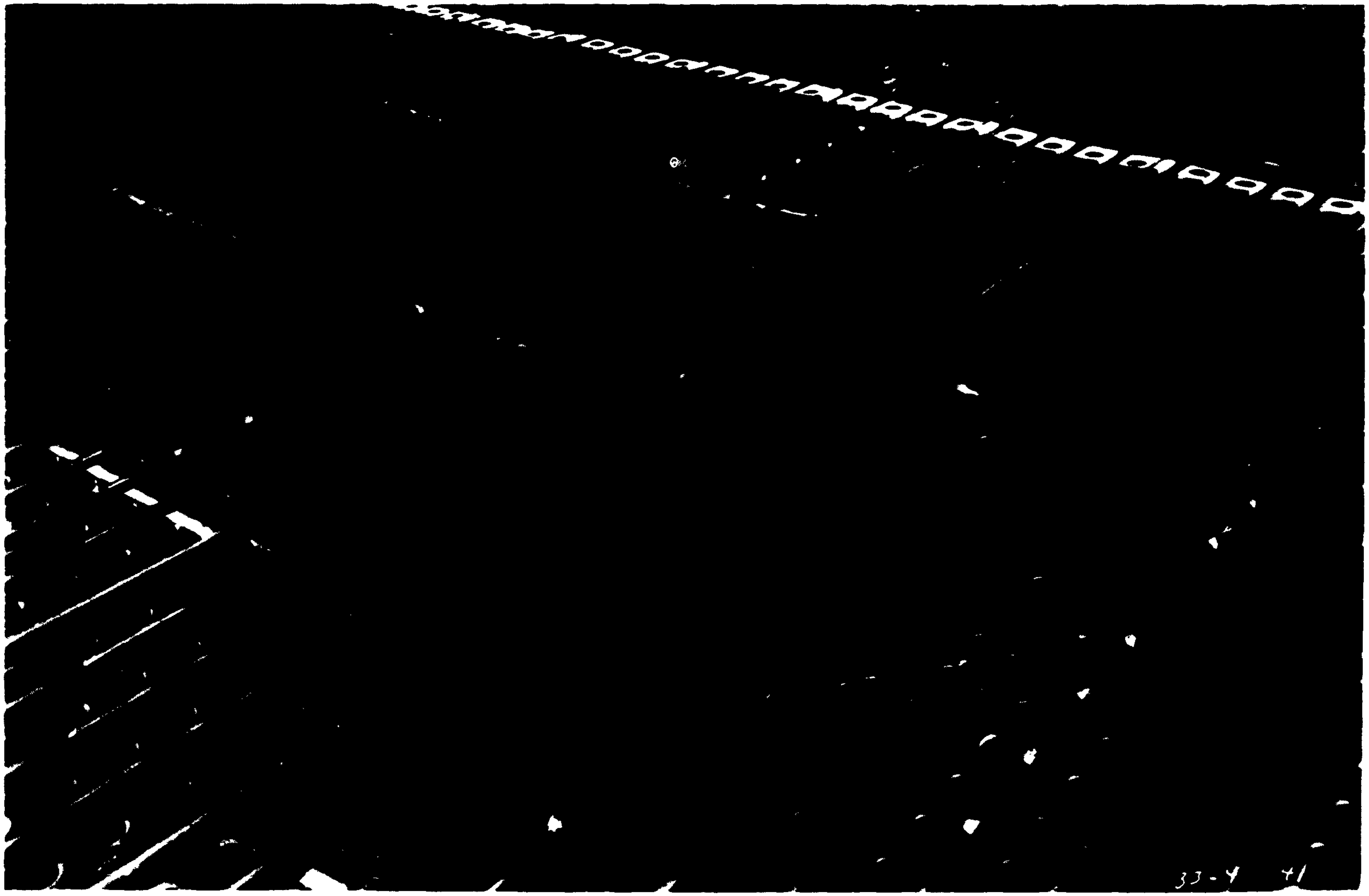
Photograph 39. Section F, lane 2, prior to start of traffic tests



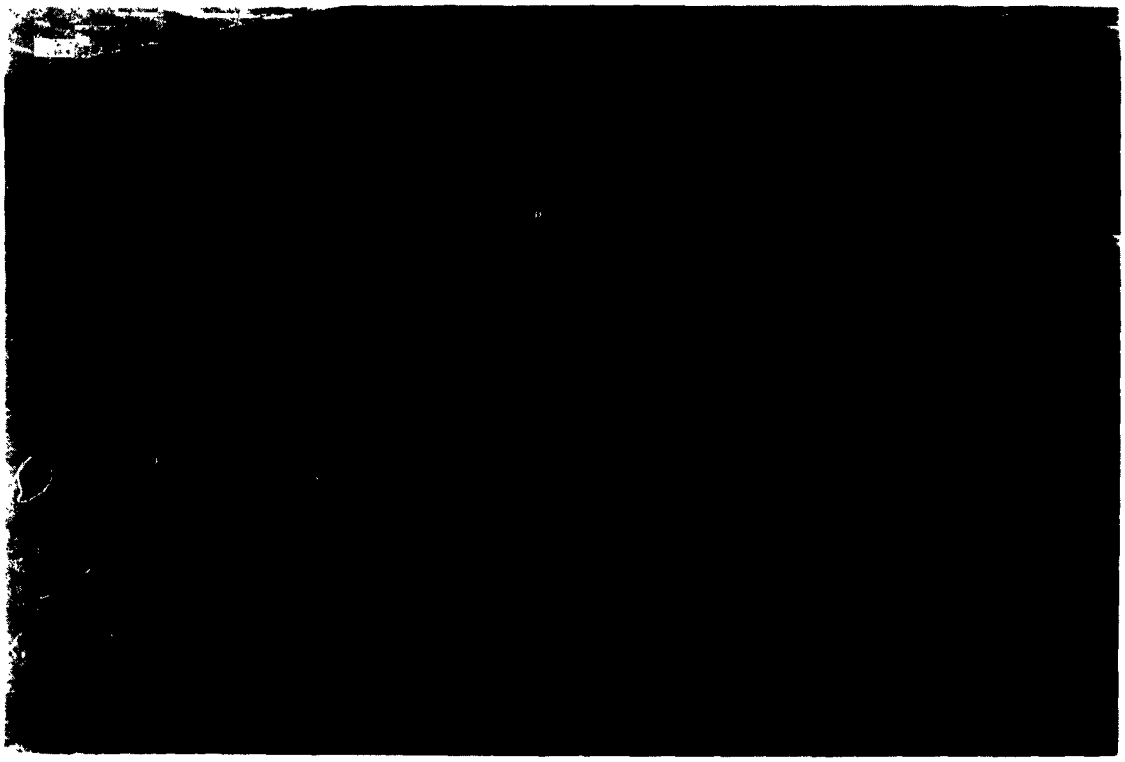
Photograph 40. Section F, lane 2, after 700 coverages

Photograph 41. Section G, lane 2, prior to start of traffic tests. (Track marks visible in photograph were made by construction equipment)

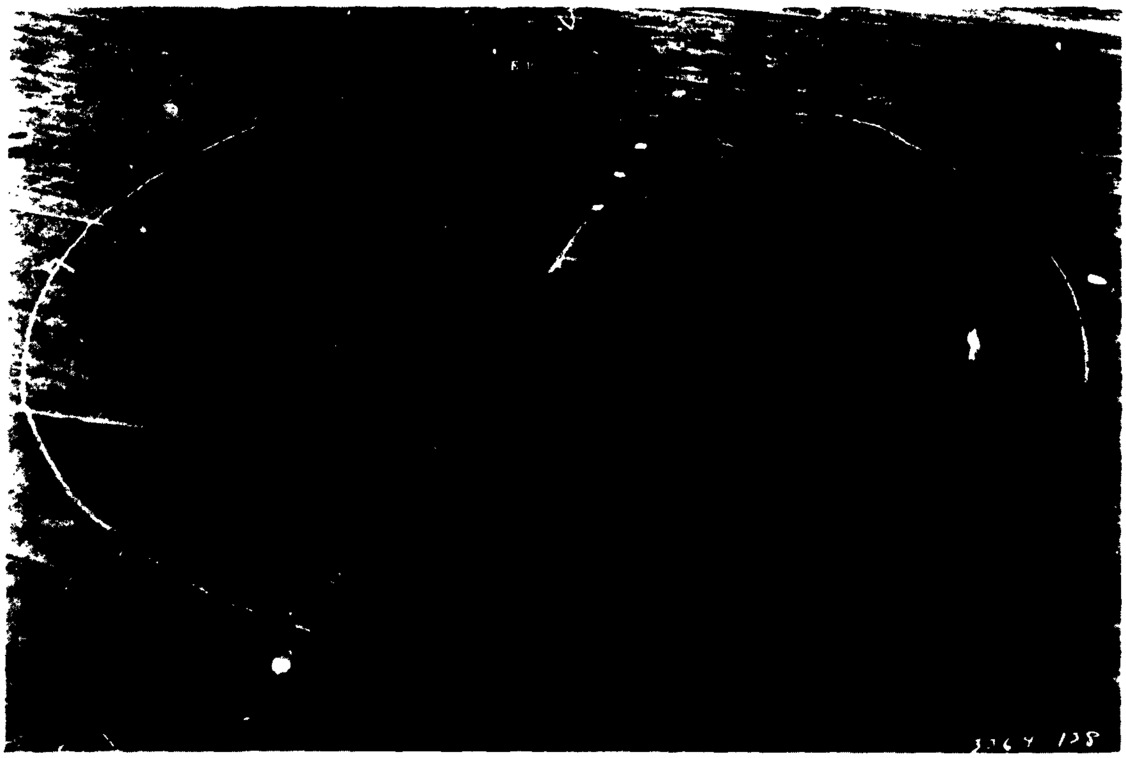
Photograph 42. Section G, lane 2, after 700 coverages



Photograph 43. Typical landing mat-membrane surfaced section after jet-engine exhaust blast. (Dots and arrows show location of thermocouples)



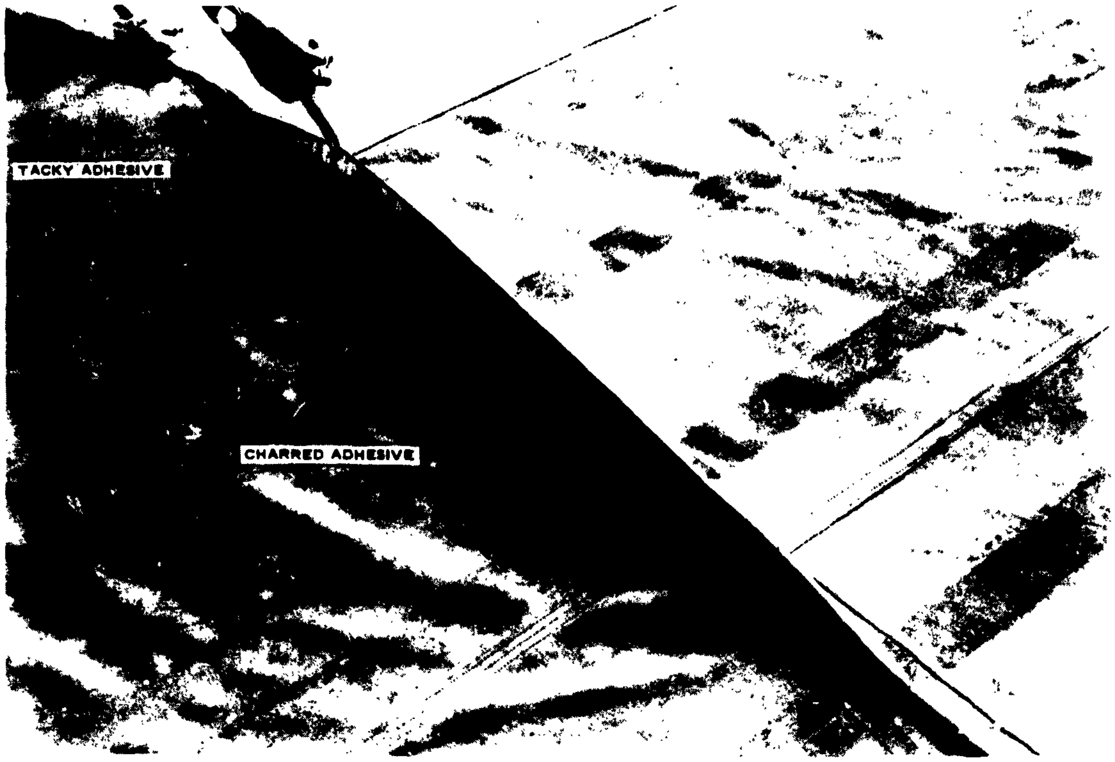
Photograph 44. T14 nylon membrane after jet-engine exhaust blast, section D, lane 2



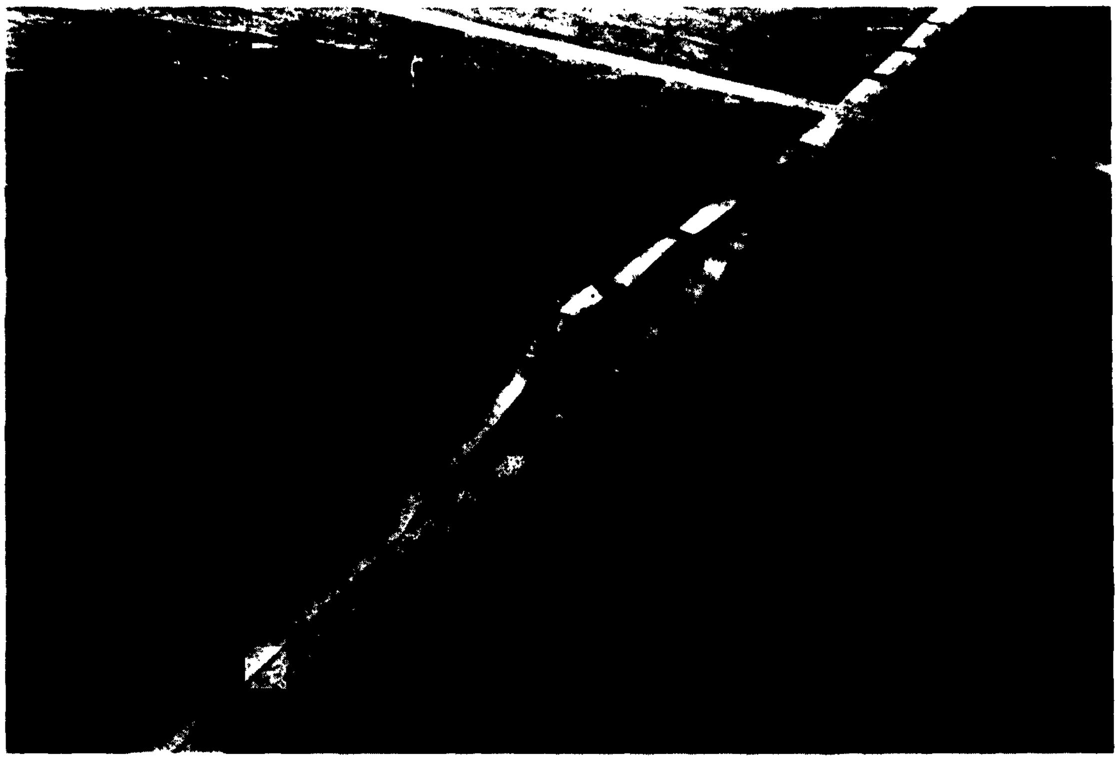
Photograph 45. T12 nylon membrane after jet-engine exhaust blast, section E, lane 2

Photograph 46. T13 nylon membrane after jet-engine exhaust blast, section F, lane 2

Photograph 47. T1 cotton duck membrane after jet-engine exhaust blast, section G, lane 2

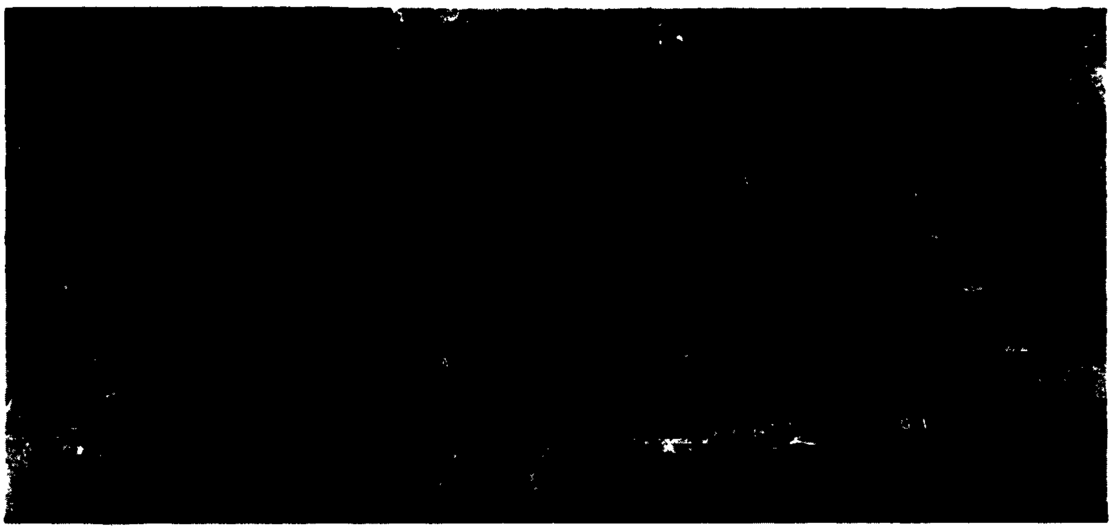


Photograph 48. Typical vinyl-adhesive joint failure from blast

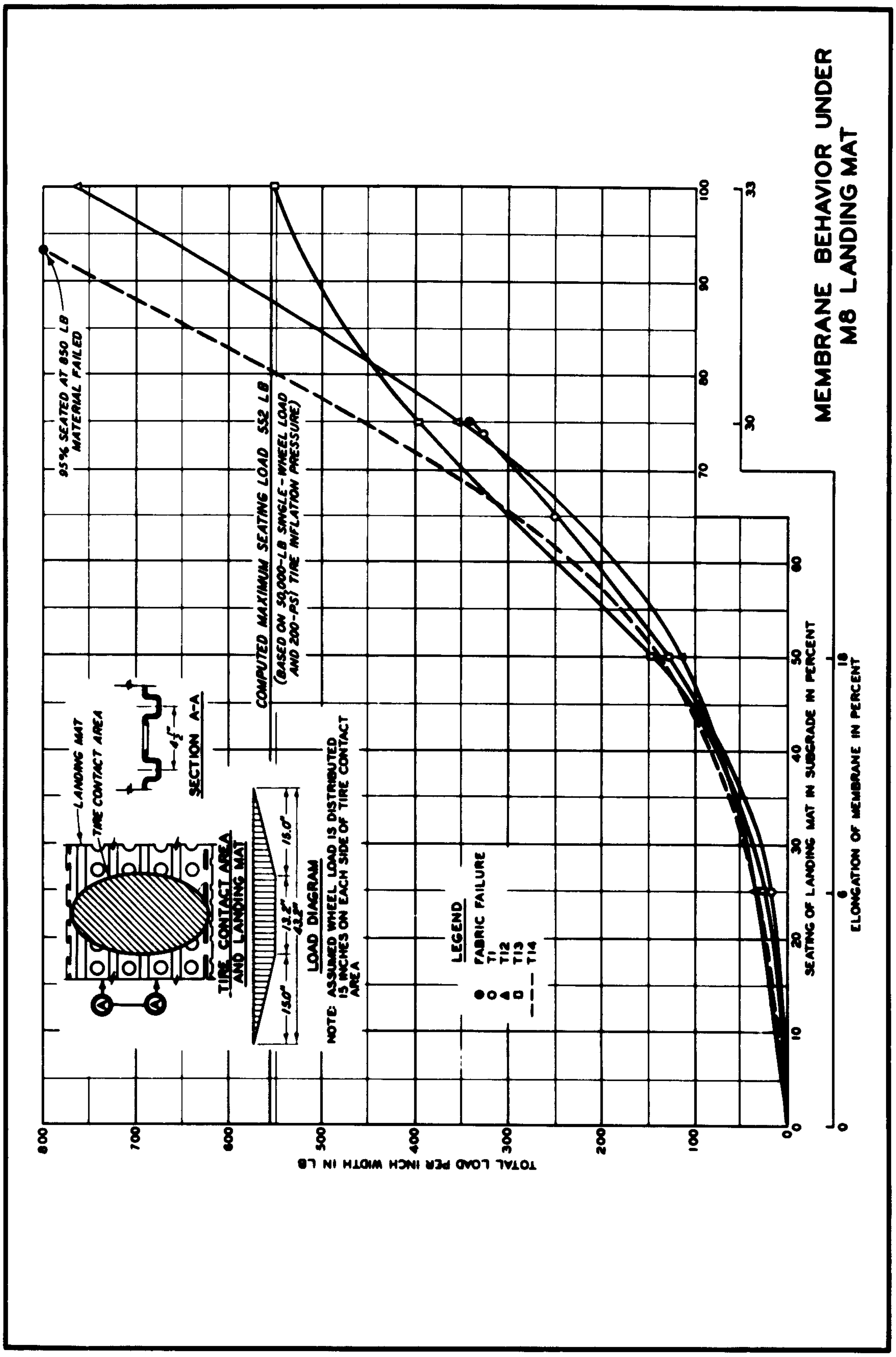


Photograph 49. Typical neoprene-adhesive joint failure from blast

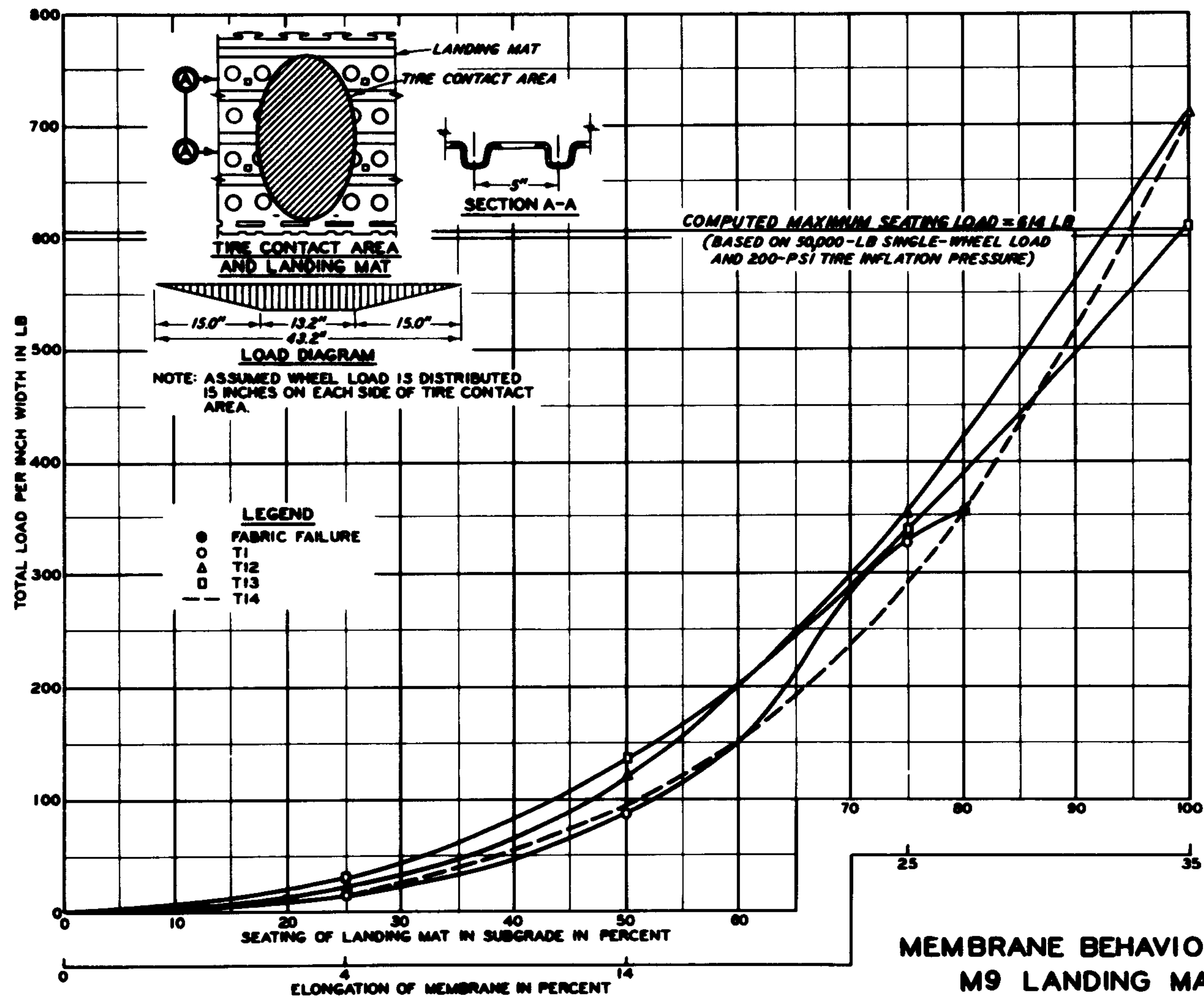
Photograph 50. Tire marks on T1 cotton duck membrane resulting from braking action of aircraft at Fort Rucker, Alabama



Photograph 51. Tire marks on T1 membrane resulting from dragging locked wheels of WES load cart across the surface



MEMBRANE BEHAVIOR UNDER M8 LANDING MAT
TOTAL LOAD PER INCH WIDTH IN LB
SEATING OF LANDING MAT IN SUBGRADE IN PERCENT
ELONGATION OF MEMBRANE IN PERCENT
95% SEATED AT 850 LB MATERIAL FAILED
COMPUTED MAXIMUM SEATING LOAD 552 LB
(BASED ON 50,000-LB SINGLE-WHEEL LOAD AND 200-PSI TIRE INFLATION PRESSURE)
LANDING MAT
TIRE CONTACT AREA
TIRE CONTACT AREA AND LANDING MAT
SECTION A-A
LOAD DIAGRAM
NOTE: ASSUMED WHEEL LOAD IS DISTRIBUTED 15 INCHES ON EACH SIDE OF TIRE CONTACT AREA
LEGEND
FABRIC FAILURE
T1
T12
T13
T14



MEMBRANE BEHAVIOR UNDER M9 LANDING MAT

PLATE 2

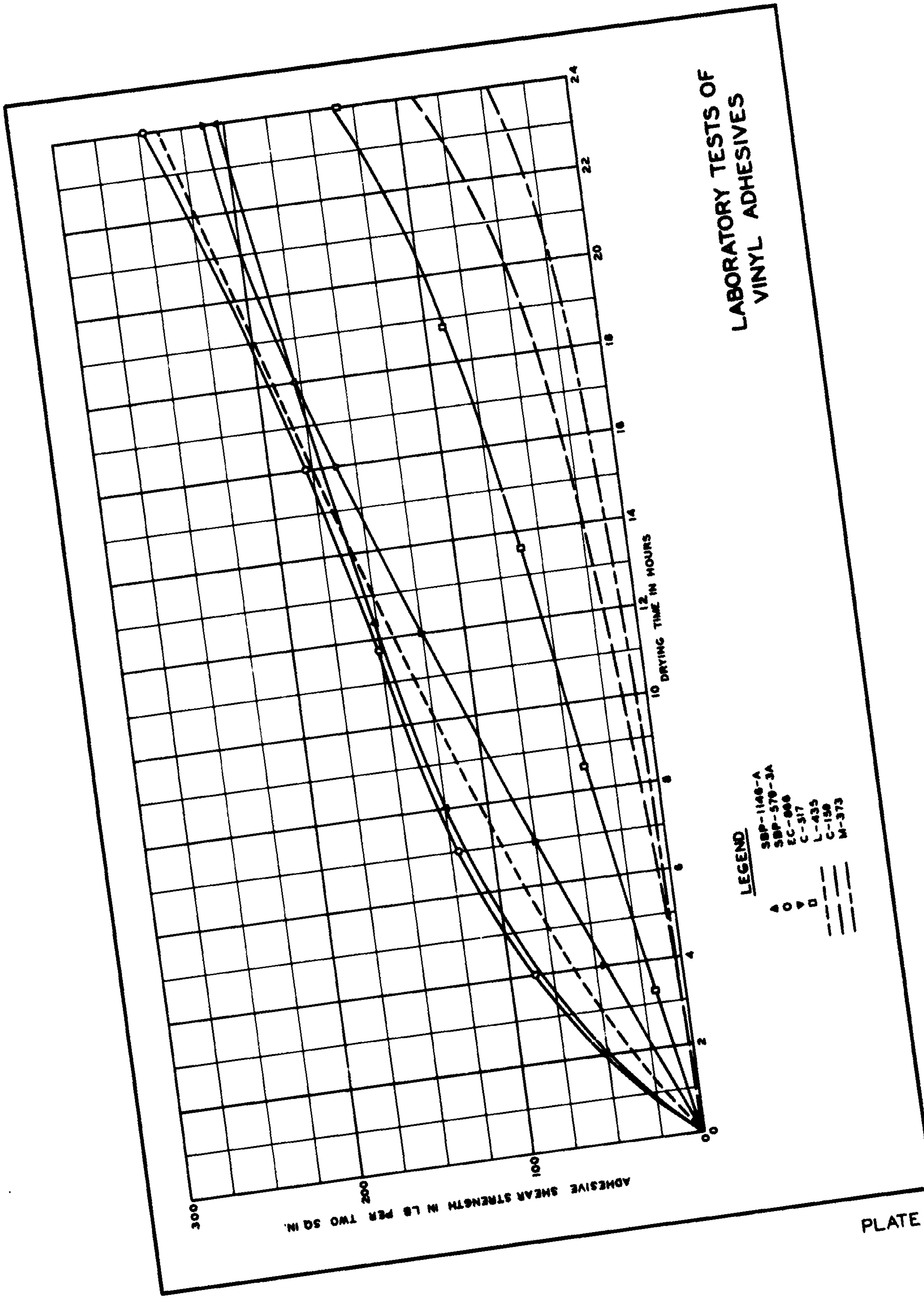

LABORATORY TESTS OF VINYL ADHESIVES
LEGEND
SBP-1146-A
SBP-579-3A
EC-866
C-317
L-435
C-150
M-373
DRYING TIME IN HOURS
0
2
4
6
8
10
12
14
16
18
20
22
24
ADHESIVE SHEAR STRENGTH IN LB PER TWO SQ IN.
100
200
300

PLATE 3

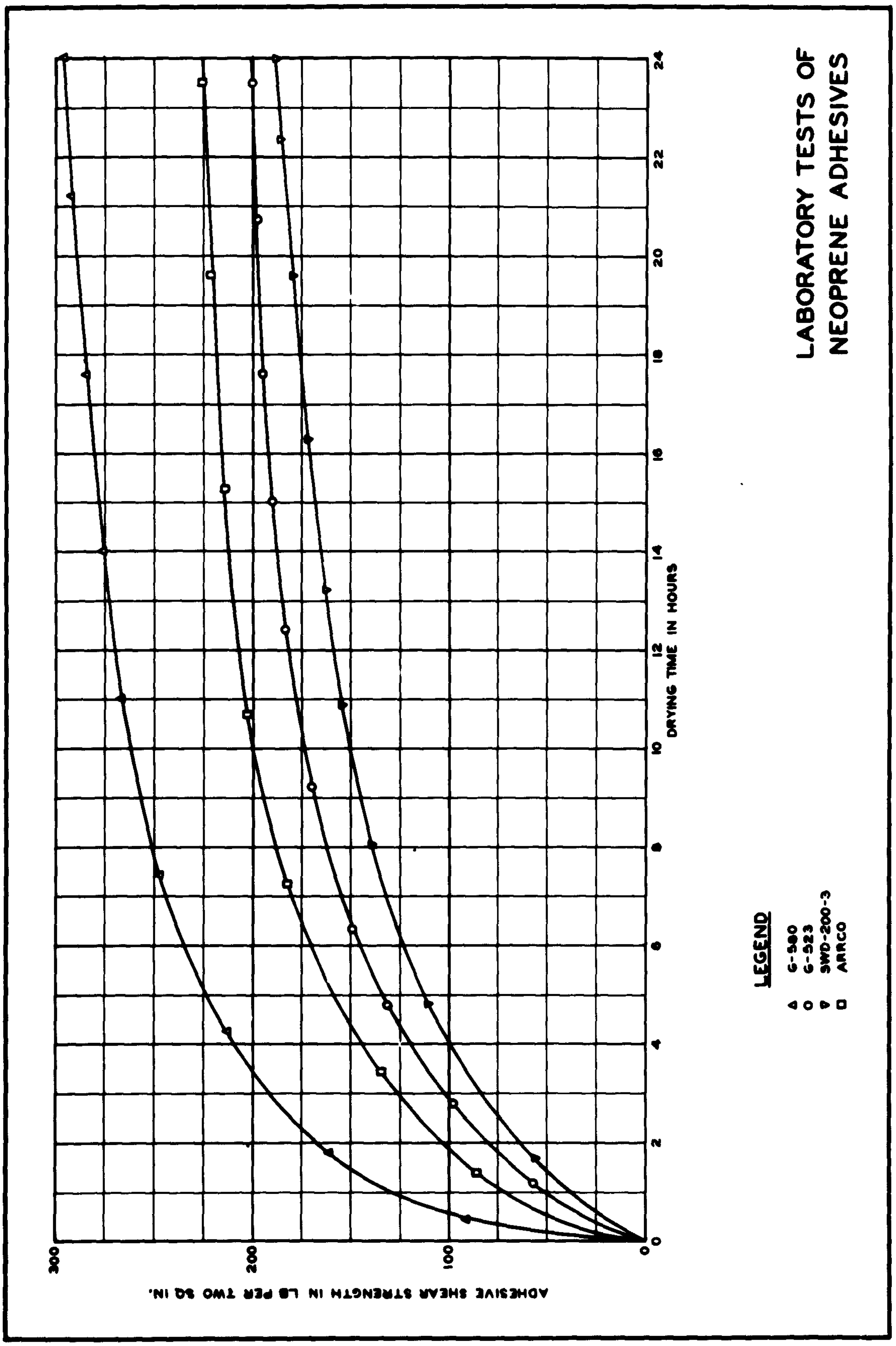
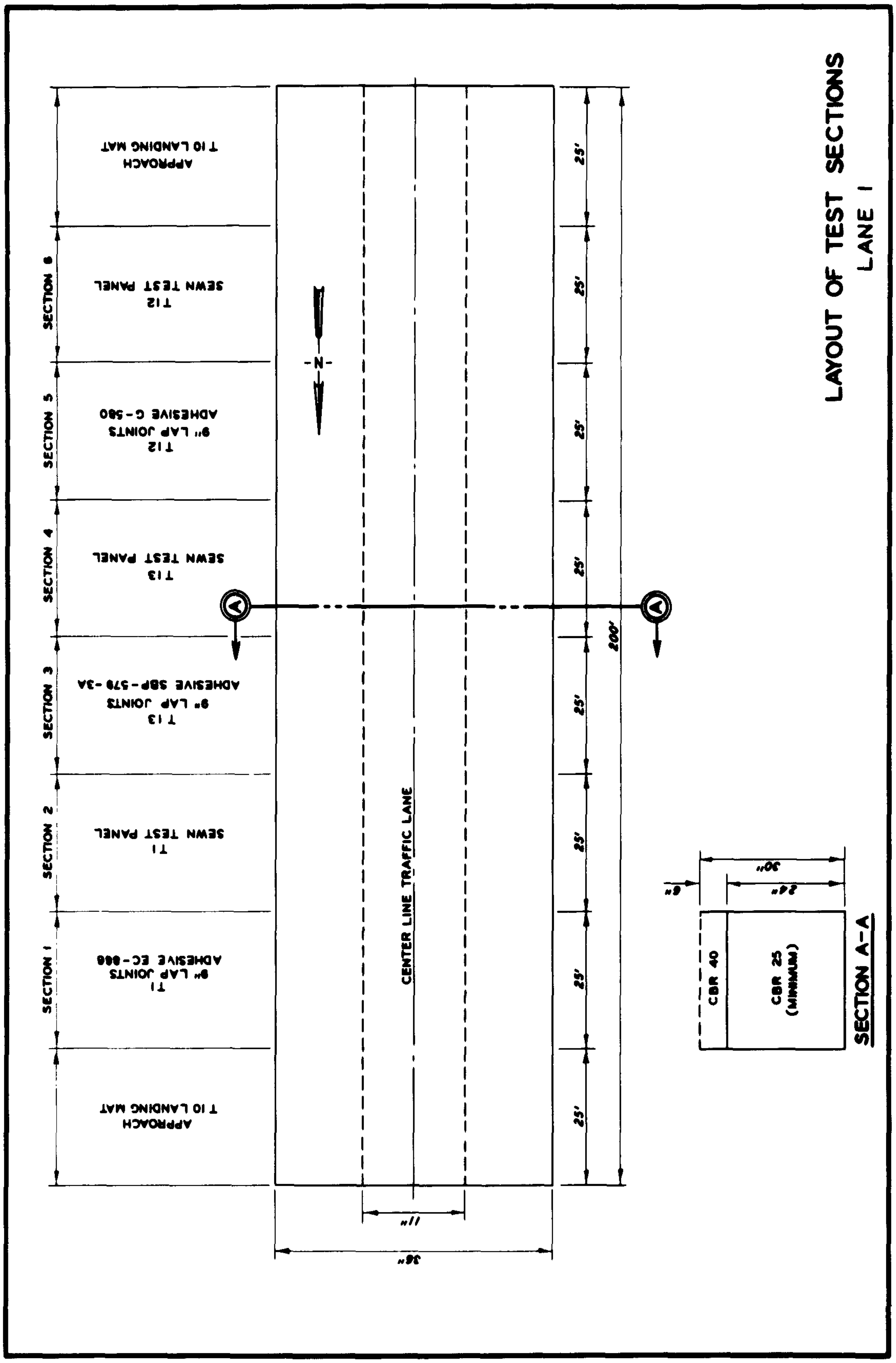
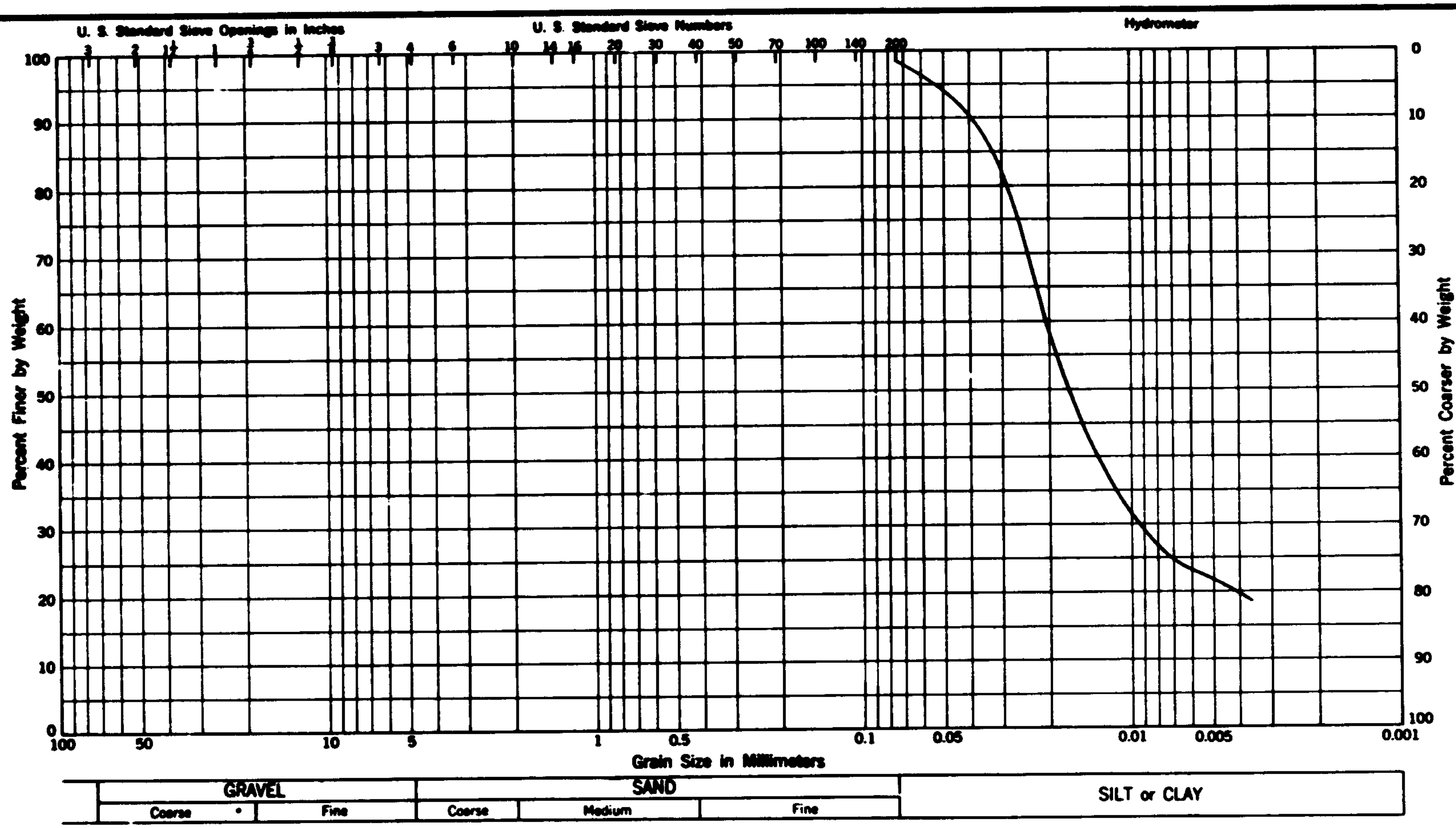

LABORATORY TESTS OF
NEOPRENE ADHESIVES
LEGEND
G-580
G-523
SWD-200-3
ARRCO
DRYING TIME IN HOURS
0
2
4
6
8
10
12
14
16
18
20
22
24
ADHESIVE SHEAR STRENGTH IN LB PER TWO SQ IN.
0
100
200
300

PLATE 4


LAYOUT OF TEST SECTIONS
LANE I
APPROACH
T 10 LANDING MAT
SECTION 6
T 12
SEWN TEST PANEL
SECTION 5
T 12
9" LAP JOINTS
ADHESIVE G-580
SECTION 4
T 13
SEWN TEST PANEL
SECTION 3
T 13
9" LAP JOINTS
ADHESIVE SBP-578-3A
SECTION 2
T 1
SEWN TEST PANEL
SECTION 1
T 1
9" LAP JOINTS
ADHESIVE EC-880
APPROACH
T 10 LANDING MAT
N
A
A
CENTER LINE TRAFFIC LANE
25'
200'
11"
36"
CBR 40
CBR 25
(MINIMUM)
6"
24"
30"
SECTION A-A



Number	Depth	Natural Moisture	L. L.	P. L.	P. I.	Classification
			34	22	12	LEAN CLAY - CL
						SP GR 2.69

CLASSIFICATION DATA

PLATE 6

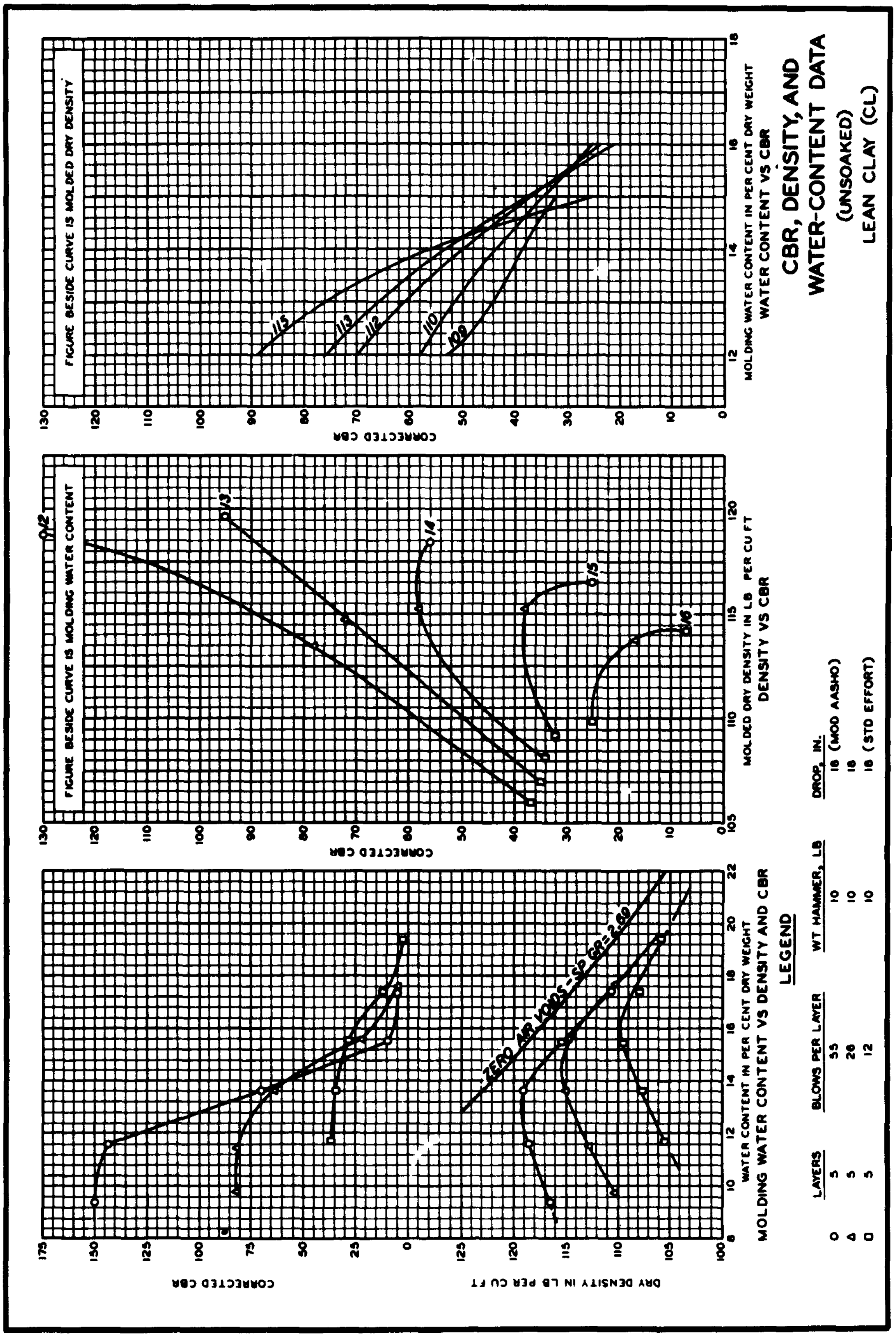
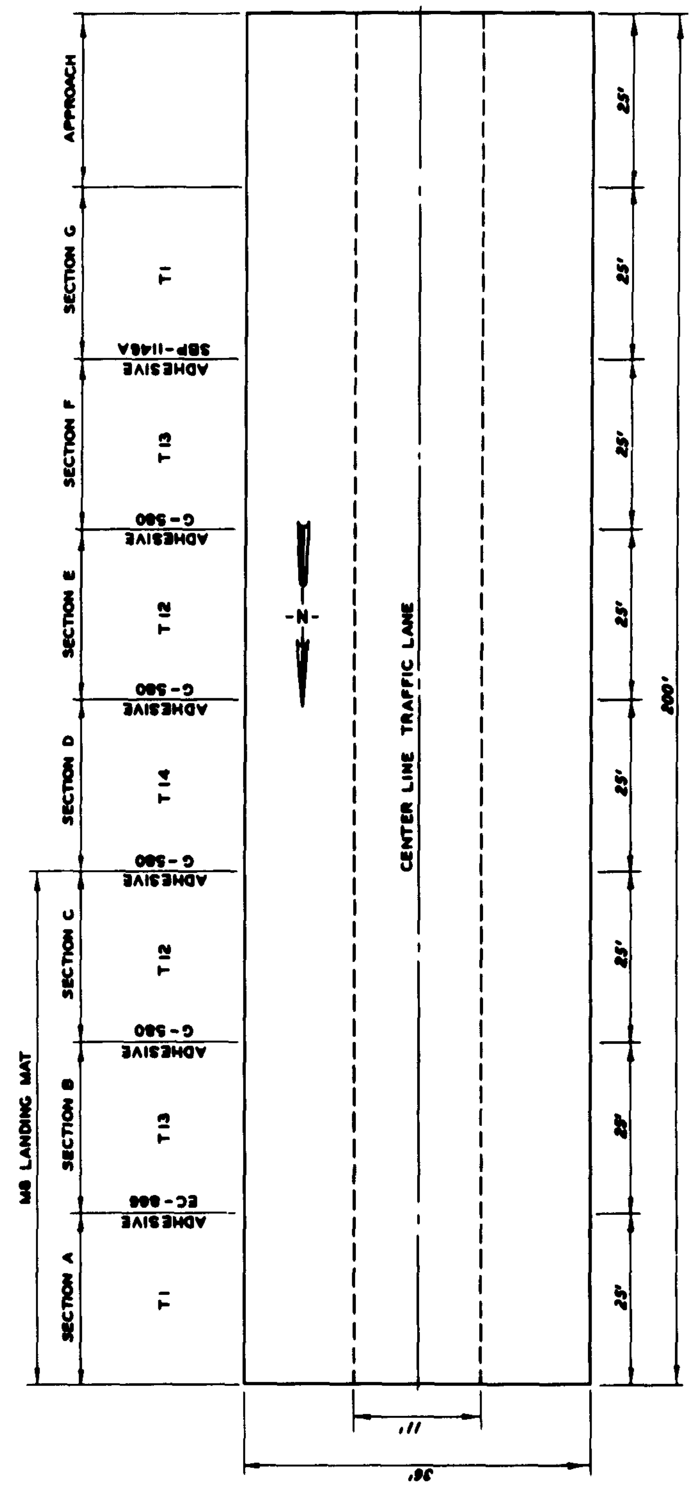


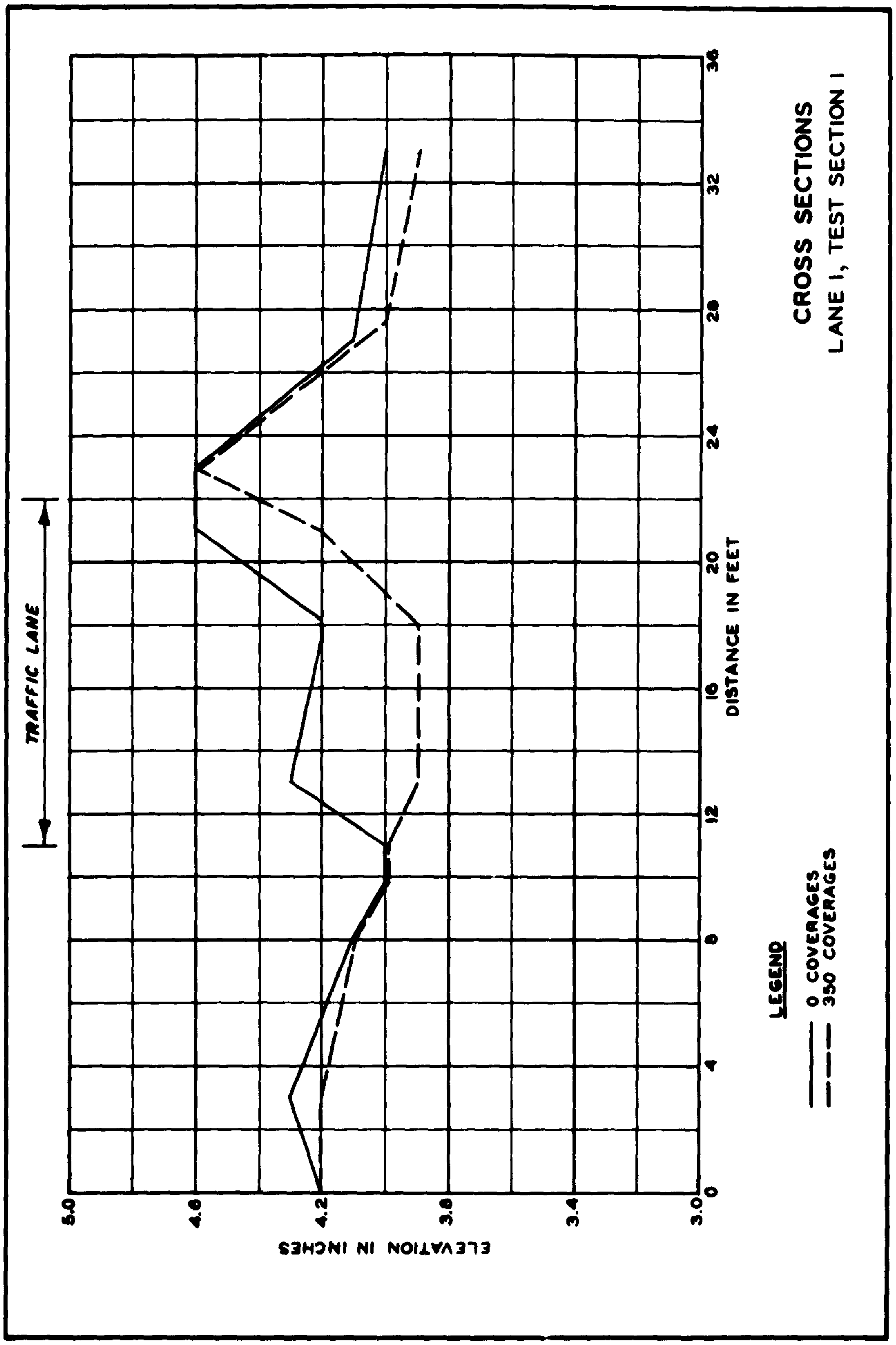
FIGURE BESIDE CURVE IS MOLDED DRY DENSITY
CORRECTED CBR
MOLDING WATER CONTENT IN PER CENT DRY WEIGHT
WATER CONTENT VS CBR
FIGURE BESIDE CURVE IS MOLDING WATER CONTENT
MOLDED DRY DENSITY IN LB PER CU FT
DENSITY VS CBR
ZERO AIR VOIDS - SP GR = 2.69
WATER CONTENT IN PER CENT DRY WEIGHT
DRY DENSITY IN LB PER CU FT
MOLDING WATER CONTENT VS DENSITY AND CBR
LEGEND
LAYERS
BLOWS PER LAYER
WT HAMMER, LB
DROP, IN.
○ 5 55 10 18 (MOD AASHO)
△ 5 26 10 18
□ 5 12 10 18 (STD EFFORT)
CBR, DENSITY, AND WATER-CONTENT DATA
(UNSOAKED)
LEAN CLAY (CL)

PLATE 7



LAYOUT OF TEST SECTIONS
LANE 2

PLATE 8


CROSS SECTIONS
LANE 1, TEST SECTION 1
TRAFFIC LANE
LEGEND
0 COVERAGES
350 COVERAGES
DISTANCE IN FEET
ELEVATION IN INCHES
0
4
8
12
16
20
24
28
32
36
3.0
3.4
3.8
4.2
4.6
5.0

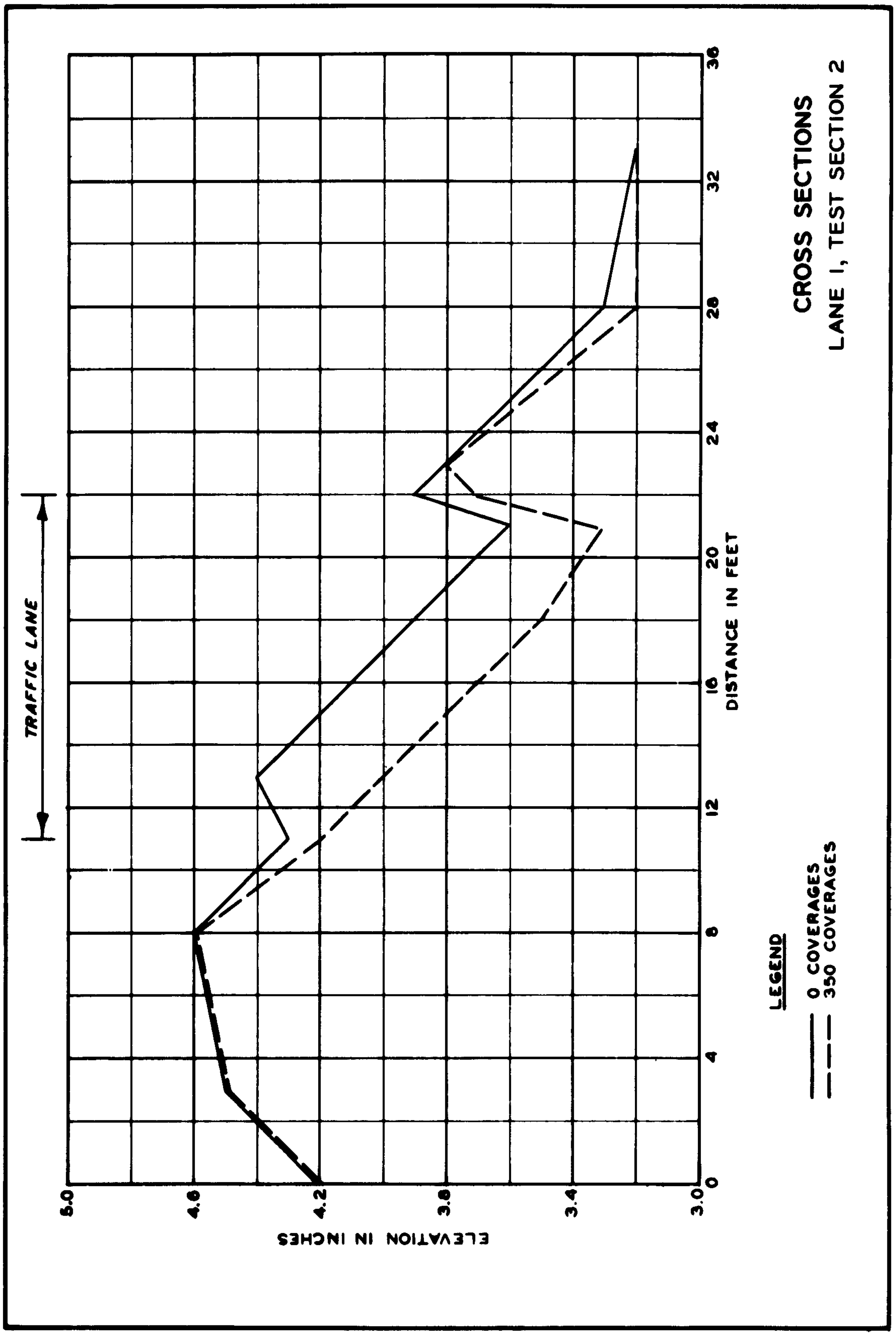
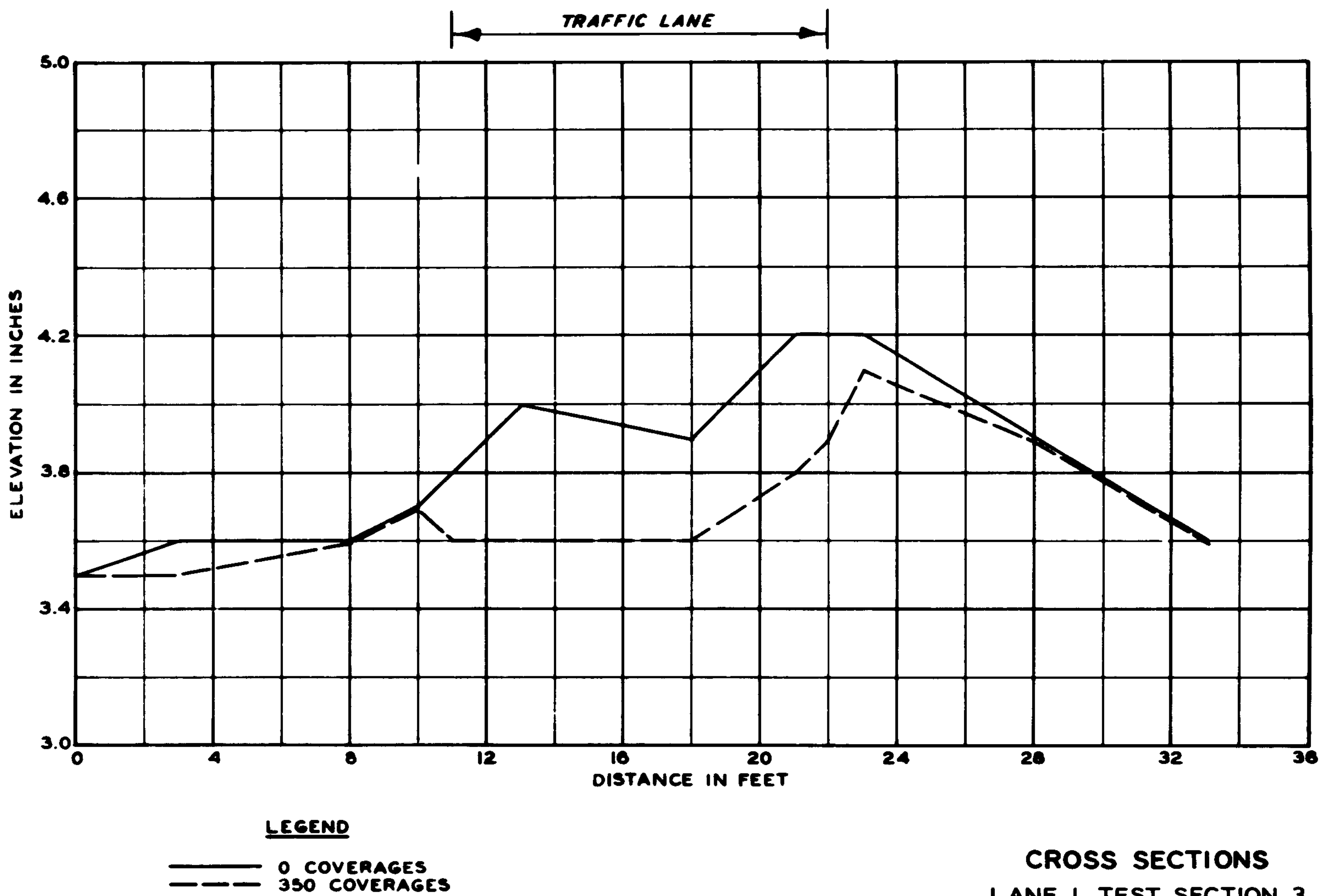

CROSS SECTIONS
LANE 1, TEST SECTION 2
TRAFFIC LANE
ELEVATION IN INCHES
5.0
4.6
4.2
3.8
3.4
3.0
DISTANCE IN FEET
0
4
8
12
16
20
24
28
32
36
LEGEND
0 COVERAGES
350 COVERAGES

PLATE 10



CROSS SECTIONS
LANE 1, TEST SECTION 3

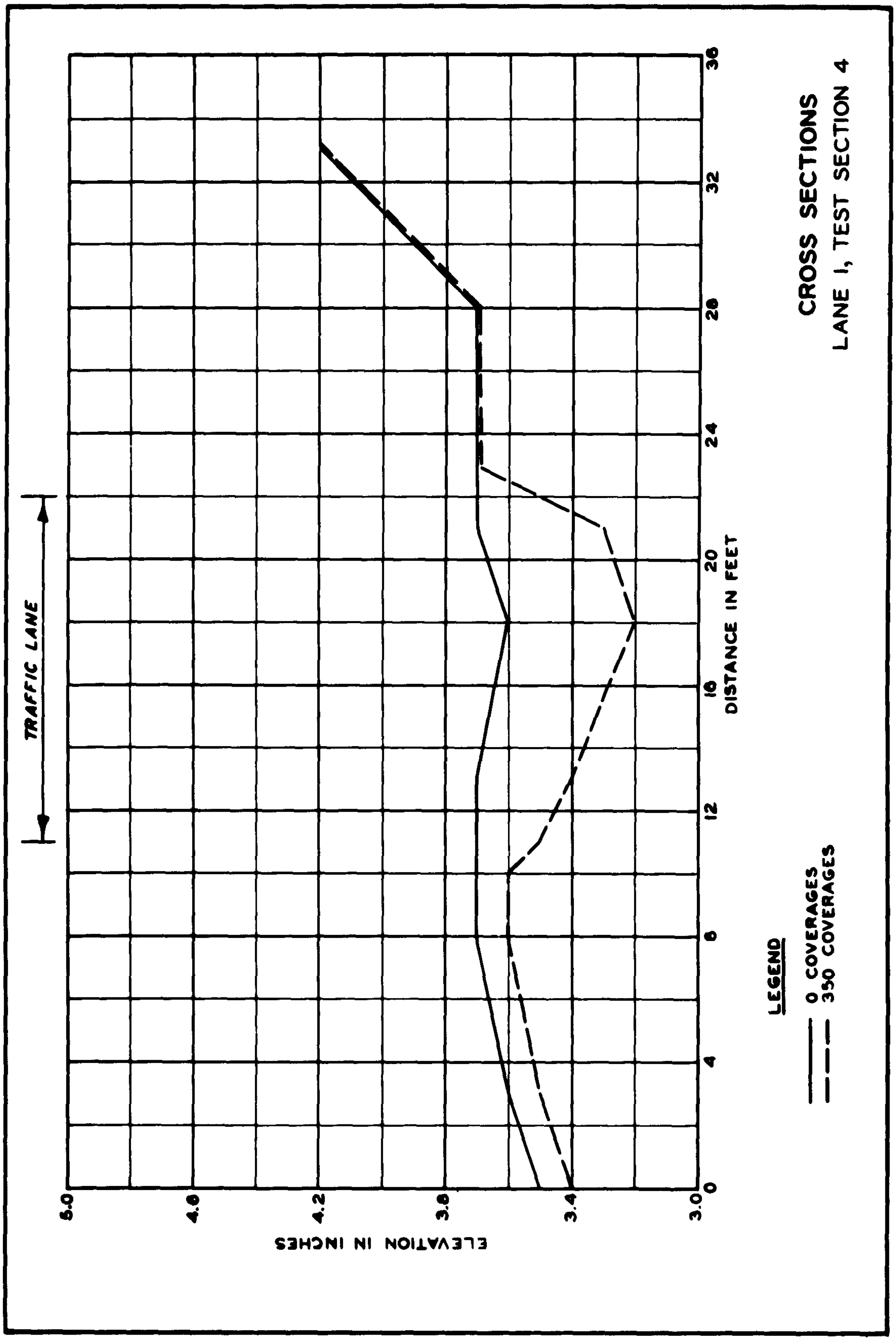
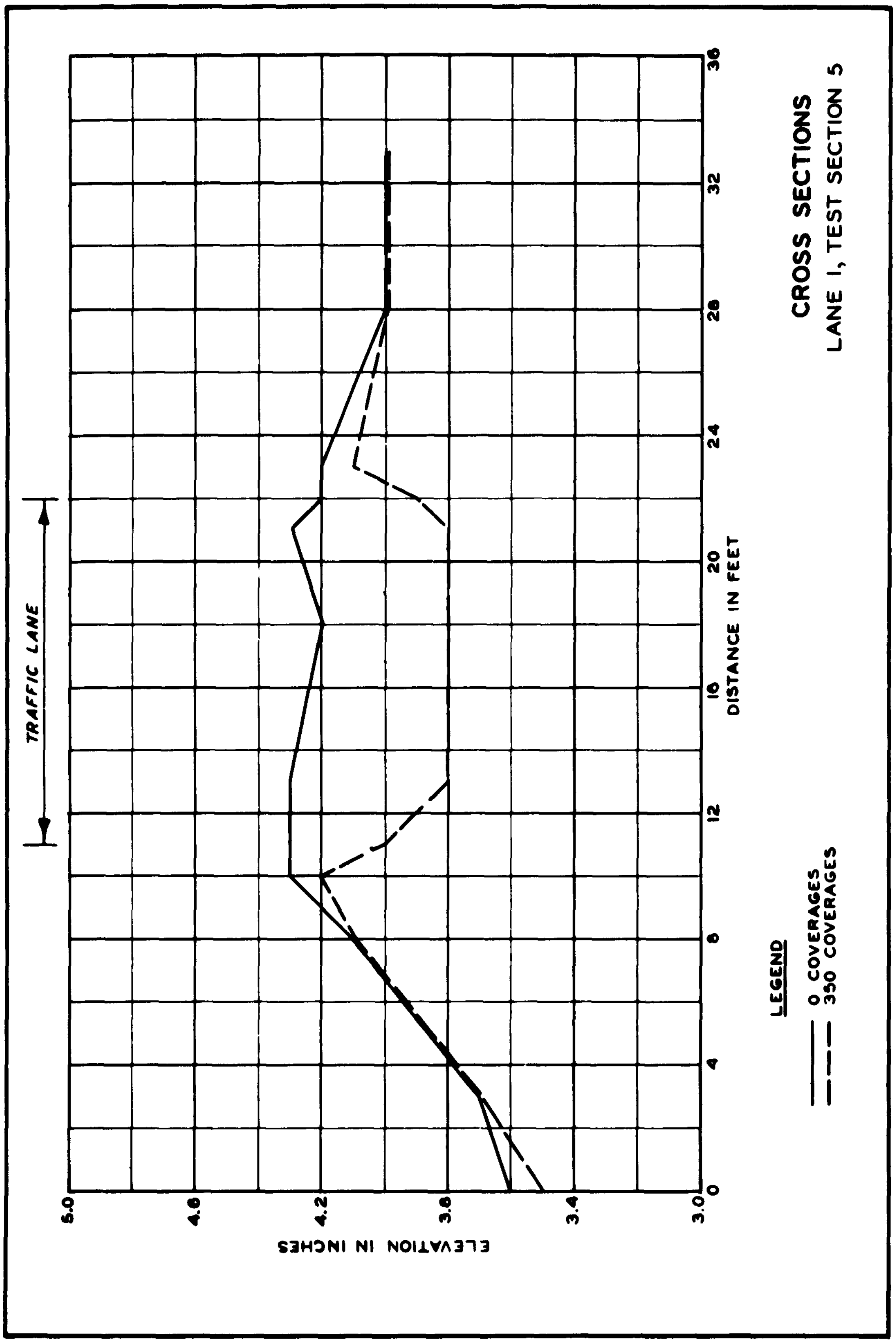
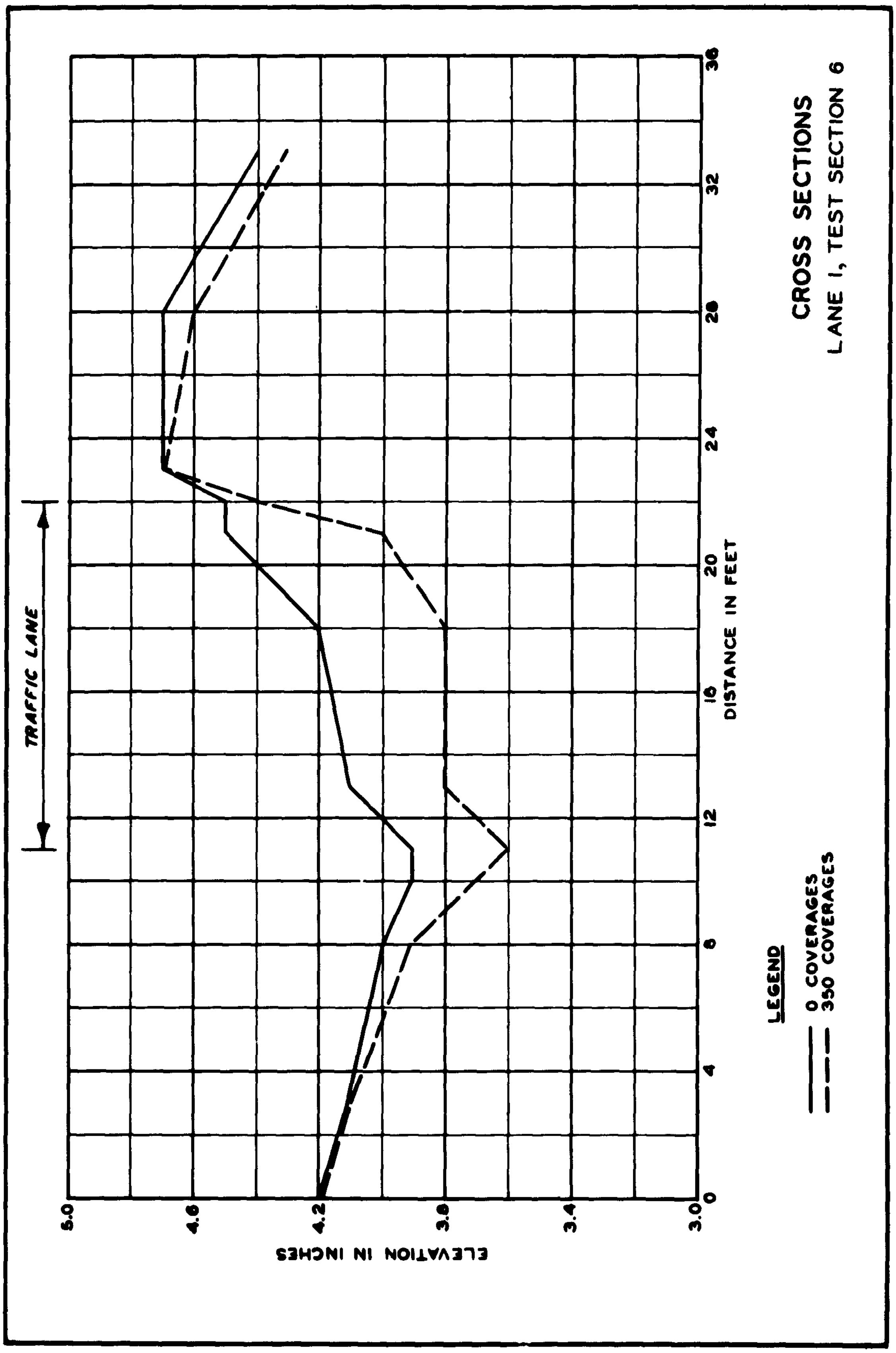
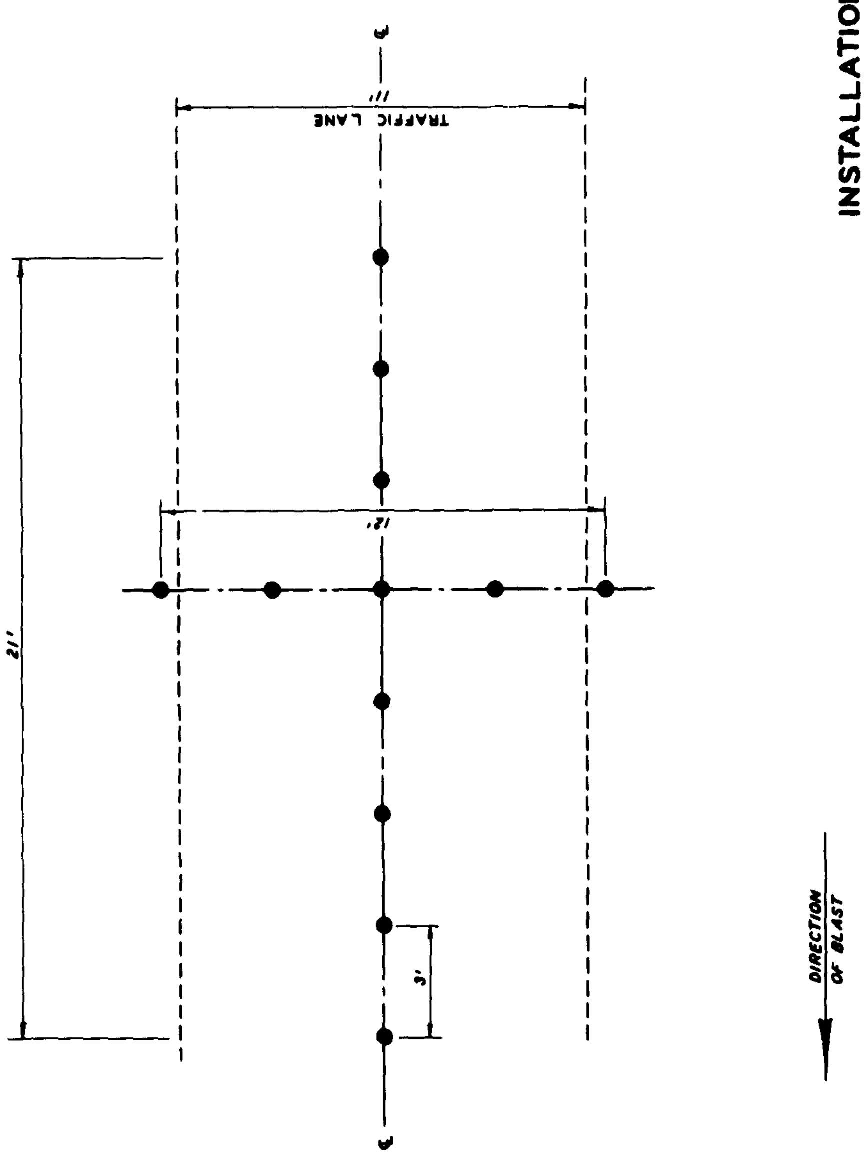

CROSS SECTIONS
LANE 1, TEST SECTION 4
TRAFFIC LANE
DISTANCE IN FEET
0
4
8
12
16
20
24
28
32
36
ELEVATION IN INCHES
5.0
4.6
4.2
3.8
3.4
3.0
LEGEND
0 COVERAGES
350 COVERAGES

PLATE 12



CROSS SECTIONS
LANE 1, TEST SECTION 5
TRAFFIC LANE
ELEVATION IN INCHES
DISTANCE IN FEET
5.0
4.8
4.2
3.8
3.4
3.0
0
4
8
12
16
20
24
28
32
36
LEGEND
0 COVERAGES
350 COVERAGES


CROSS SECTIONS
LANE 1, TEST SECTION 6
TRAFFIC LANE
DISTANCE IN FEET
0
4
8
12
16
20
24
28
32
36
ELEVATION IN INCHES
3.0
3.4
3.8
4.2
4.6
5.0
LEGEND
0 COVERAGES
350 COVERAGES



INSTALLATION OF THERMOCOUPLES
SECTION C, LANE 2

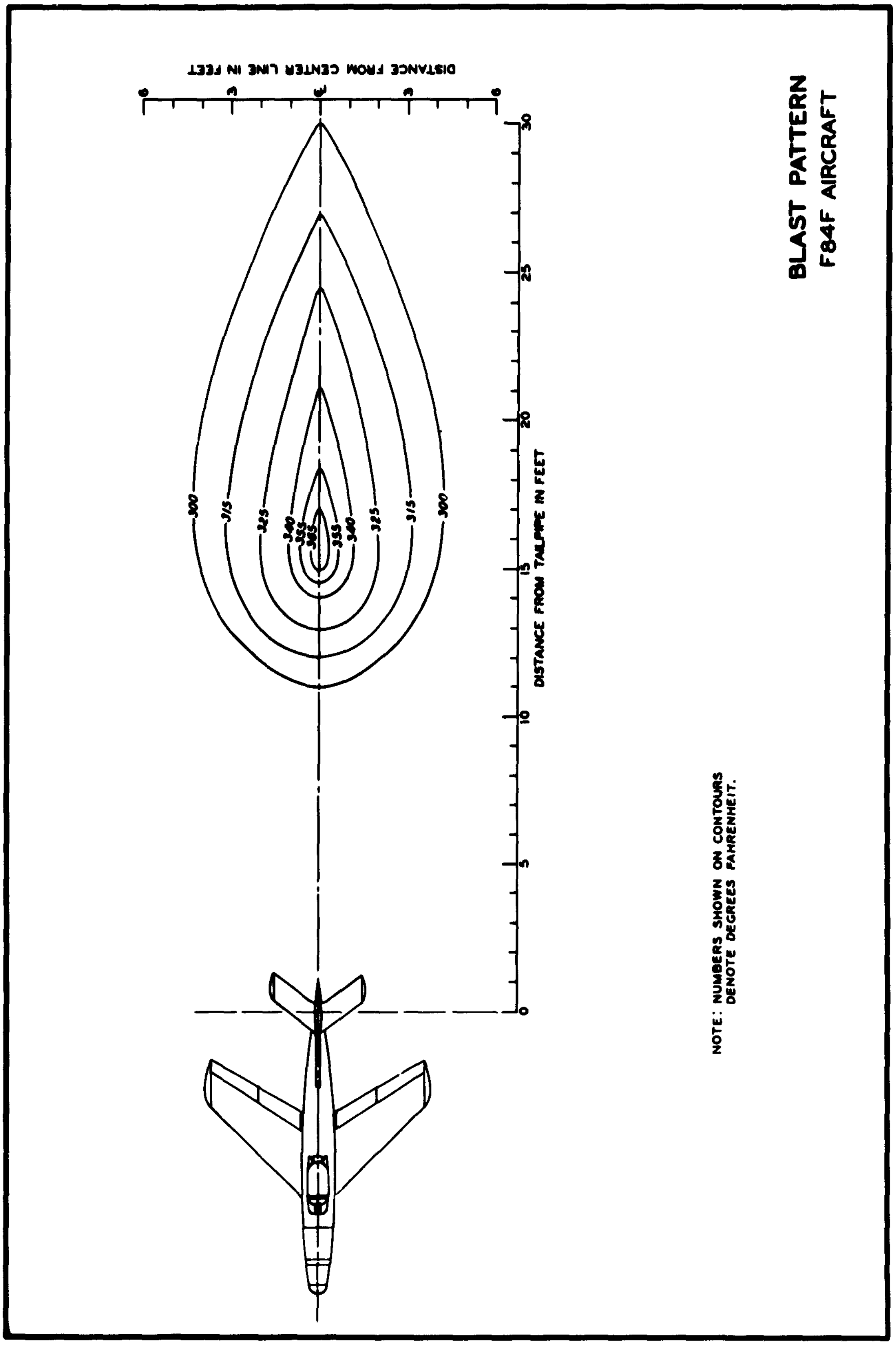

BLAST PATTERN
F84F AIRCRAFT
NOTE: NUMBERS SHOWN ON CONTOURS
DENOTE DEGREES FAHRENHEIT.
DISTANCE FROM TAILPIPE IN FEET
DISTANCE FROM CENTER LINE IN FEET
300
315
325
340
355
365
0
5
10
15
20
25
30
6
3
℄
3
6

PLATE 16

APPENDIX A: PROJECT CARD

Subproject of Project 8-70-03-100

R & D PROJECT CARD	TYPE OF REPORT: PROGRESS	REPORT CONTROL SYMBOL

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
PREFABRICATED AIRFIELD AND ROAD SURFACING MEMBRANE (PRFB ARFLD-ROAD-SUR)	UNCLASSIFIED	8-70-03-101
	4. INDEX NUMBER: CETC NO. 1911/217	5. REPORT DATE: 31 Dec 1955

6. BASIC FIELD OR SUBJECT	7. SUB FIELD OR SUBJECT SUB GROUP	7A. TECH. OBJ.
Soils and Surfacing	Soils Treatment and Surfacing	SO-13

8. COGNIZANT AGENCY: Corps of Engineers

9. DIRECTING AGENCY: Engr Res & Dev Div, MO, OCE

10. REQUESTING AGENCY: Office, Chief of Engineers; Dept of the Air Force

12. CONTRACTOR AND/OR LABORATORY: Waterways Experiment Station (see block 19)

CONTRACT/W. O. NO.

11. PARTICIPATION AND/OR COORDINATION:
Dept of the Air Force (C)
Dept of the Navy (C)
Army Field Forces (C)

13. RELATED PROJECTS:
8-70-03-102
8-70-03-103
8-70-03-106

17. EST. COMPLETION DATES

RES.	Feb 53*
DEV.	Jul 55
TEST	Dec 55
OP. EVAL.	Dec 56

18. FY.	FISCAL ESTIMATES

14. DATE APPROVED: 12 January 1951 by GSUSA

15. PRIORITY: 1-C

16. MAJOR CATEGORY: P5121

19. REPLACED PROJECT CARD AND PROJECT STATUS: Supersedes Project card 8-69-03-001 dated 31 December 1954. Responsibility for project transferred from ERDL to WES 1 July 1954 by OCE letter 2 February 1954 to ERDL and WES, subject, "Centralization of Soils and Related Programs."

20. REQUIREMENT AND/OR JUSTIFICATION: There is a requirement for an improved type of prefabricated airfield and road surfacing membrane for dust and waterproofing soil bases on which airplane landing mats are to be placed; and for the temporary surfacing of roads and runways in Theaters of Operations. The existing membrane (PBS) is too limited as to availability of materials, strength, durability in storage, and adaptability to use in areas of extreme temperatures, to satisfy these requirements. This development will result in a material, the lack of which would prevent the timely accomplishment of important assigned missions of the using agencies.

21. BRIEF OF PROJECT AND OBJECTIVE

a. Brief:

(1) Objective:

The development of a flexible prefabricated airfield and road surfacing membrane suitable as a dustproofing and waterproofing medium for soil bases on which airplane landing mats are to be placed and as a temporary surfacing for roads and runways in all theaters.

(2) Military Characteristics:

(a) The membrane shall be composed of materials that can readily be made available in the U. S. in time of war.

(b) The membrane shall preferably be a composite of materials that will not support combustion.

22. OASD (R & D)	SN.	CN.	C.	X.	I.	C.

DD FORM 613, 1 APR 55 — REPLACES DD FORM 613, 1 JAN 52.

* Additional development on adhesives is necessary.

R&D PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
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(c) The membrane shall be resistant to the deleterious effects of engine fuels, engine coolants, lubricants, de-icer fluids, and hydraulic fluids.

(d) The membrane shall be capable of fabrication in production-type plants, preferably in commercial plants already established.

(e) The membrane shall be capable of being placed rapidly by machine methods at ambient temperatures from approximately +20 F to +125 F to form a continuous waterproof surface for roads or runways, and must be capable of safe storage in the open for 3 years without rotting, distortion, sticking, or deterioration, at temperatures from -80 F for periods of several days at a time to +160 F for periods of at least 4 hours daily, under all conditions of humidity.

(f) The membrane shall have sufficie strength, toughness, and flexibility when placed in two overlapping layers to support operations of aircraft exerting 50,000-lb single-wheel loads and tire contact pressures of 200 psi, when in normal usage, for 6 months. Also it shall withstand the stresses and abrasion caused by a landing mat surface, when in normal usage, for 6 months.

(g) The durability of the membrane shall be such that when placed in two overlapping layers, on a subgrade with adequate bearing power, it shall be capable, with minimum maintenance, of withstanding 350 coverages of the above specified wheel load and tire contact pressure.

(h) The membrane shall be resistant to the deteriorating effects of jet aircraft and rocket assist blasts up to 350 F.

(i) The weight of a single layer of the membrane shall not exceed 6 lb per sq yd.

(j) The membrane shall be manufactured in strips approximately 40 in. wide and packaged in rolls weighing a maximum of 500 lb.

(k) Splices within roll lengths of the membrane shall be avoided. When splices are unavoidable, they shall be securely fastened and waterproof.

(l) The centerline of the membrane strips shall be marked with a continuous easily seen line.

(m) The membrane shall be capable of rapid maintenance and repair in the field.

(n) Air transportability is required in Phase I of Airborne Operations.

b. Approach:

(1) It is desirable that a single membrane type be developed that will satisfy requirements in all theaters. However, since conditions are so varied, considerable difficulty is anticipated in selecting a material or combination of materials that will be satisfactory for use in both hot and cold extremes of climate, and it is recognized that this project may result in recommendations for classification of more than one type of membrane.

(2) A study will be made of the available materials, and materials that can readily be made available, for the manufacturer in quantity of a flexible membrane with the desired characteristics. Initial emphases will be

R&D PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
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placed on development of a dustproofing and waterproofing membrane for use under landing mat.

(3) One or more promising materials will be selected for experimental quantities of the membrane. Engineering tests of the experimental membranes will be conducted to determine their adequacy for the intended use. Tests of the dustproofing and waterproofing qualities when used under airplane landing mat will be coordinated, if possible, with other tests of airplane landing mats.

(4) Recommendations will be made for service tests to be conducted by USAF.

(5) If service tests prove successful, specifications will be prepared and classification of equipment action will be recommended.

c. Subtasks:

(1) Ultimate completion of the over-all development of improved prefabricated road and runway surfacing should include the development of an adequate machine for placing the surfacing rapidly. It is contemplated that another project will be requested to cover that phase of the development when the improved membrane has been successfully developed.

(2) Under Project 8-70-03-102 M8 and M9 metal landing mats have been developed and under Project 8-70-03-103 plastic landing mats are being developed. Project 8-70-03-106 is for the development of a method of dustproofing and waterproofing soils under landing mat. All three of these projects are interrelated to this new project as expedient surfacing materials for advanced airfield runways.

d. Other Information:

(1) References:

(a) Report, 10 February 1945; "16 Miles of Hessian Surface," U. S. Army numbered Hq. 2nd Engineer Aviation Brigade IX EC, tells of the inadequacy of existing membrane (PBS) for placing at temperatures below 45 F and of trouble in construction caused by the adhesion of layers in rolls and misshaped rolls as a result of shipping and storage.

(b) Report, 24 October 1946, "Prefabricated Bituminous Surfacing for Runways for Heavy Airplanes," indicated that the new high pressure tires will damage the existing membrane (PBS) and that increased tensile strength in an improved type should reduce maintenance.

(c) Report, "Performance of PBS (of Indian Manufacturer) in Storage over 2 to 3 Years, W/Letter from British Army Staff to ERDL," dated 16 December 1947, indicates inadequacy of the present membrane (PBS) to withstand storage for any extended period of time without undue deterioration.

(d) "Minutes of Meeting Held to Discuss W. O. Specification for PBS," dated 29 October 1948, covers a discussion of the need for a considerably improved PBS.

(e) "Trafficability of Soils, Tests on Self-Propelled Vehicle, Yuma, Arizona, 1947," indicates the inadequacy of the present membrane (PBS) to withstand storage for any extended period of time without undue deterioration.

DD FORM 1 FEB 50 613-1
REPLACES DD FORM 613-1, 1 FEB 50.

R&D PROJECT CARD
CONTINUATION SHEET

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(f) Letter from the Chief of Staff, Department of the Air Force, to the Chief of Engineers dated 14 March 1949, file AFM10-4C/1, subject, "Development of an Improved Prefabricated Surfacing," with one indorsement, which requested the establishment of a project for the development of an improved prefabricated surfacing membrane.

(2) Discussion:
Agencies interested in this project, in addition to the Corps of Engineers, with which liaison will be maintained and which will be furnished copies of reports on the project are the Department of the Air Force, Department of the Navy, Army Field Forces, and Transportation Corps.

(3) Scientific Research:
Significant research performed within this project is described as follows:
Under contract DA 44-009-eng-791 the Irvington Varnish and Insulator Company performed a research task in the derivation of a formula to be used in the evaluation of membranes from laboratory test results.

(4) Standardization Item:
Items developed under this project appear as Integrated List Sheet Number 3-2-2-7 on the Tripartite Standardization Program.

(5) Engineering Test (Production and/or Use Limitations):
Not applicable because no items of equipment developed under this project are estimated to be released to production in 1956.

(6) Operational Availability Date:
The membrane developed under this project is estimated to be acceptable for release to users by December 1957.

(7) Same or Related Items:
None.

(8) Specific Review Points:
Not applicable since engineering design is not complete.

(9) Fund Estimate: (see basic project)

e. Background History and Progress:

(1) Cumulative Background History.

A history of the significant technical progress on this project since its approval on 12 January 1951 and to 31 December 1955 follows:

The development of prefabricated airfield and road surfacing membranes was initiated prior to above approval date under Project 8-70-03-001, "Dustproofing and Waterproofing Soils under Landing Mats."